STEVEN J. CARR, Environmental Air Monitoring Of Tritiated Water Vapor From Incinerator Emissions - Conducted For The National Institute Of Environmental Health Sciences (Under the direction of DR. ALVIS TURNER AND DR. JAMES WATSON)

ABSTRACT

Sampling and analysis was performed on ambient air potentially contaminated with tritiated water vapor from incinerator stack emissions. A sampler designed for monitoring tritium was modified for monitoring brief sampling periods during 1-2 day long incinerator operations. Modeling indicated that the sampler potentially can detect tritium emissions from the incinerator stack when the wind is blowing directly towards the sampler (± 8°) and the maximum allowable concentration is being released. Under these conditions, a worker near the point of sampling for a whole year could potentially receive .1% of the occupational dose limit or 2.5% of the general public dose limit. Since the wind conditions vary significantly and

the maximum concentration is not continuously released, actual dosage would be much less.

The results from actual sampling events indicated that the sampling/analysis system was not sensitive enough to detect ambient air concentrations. Although the sampling results were below detection limits, an extraction procedure was developed which may be utilized in other applications where airborne tritium concentrations are higher.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF EQUATIONS

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I. INTRODUCTION

The National Institute of Environmental Health Sciences (NIEHS) is a federal research facility located in Research Triangle Park, North Carolina and is one of the National Institutes of Health (NIH). The NIEHS's primary mission is to study the effects of environmental agents on human health. To accomplish this task, radioisotopes are utilized by researchers as tracers to better define the biomedical impacts of various environmental agents. NIEHS's policy is that these radioisotopes be utilized and disposed of in a manner which will ensure the safety of the facility personnel and the local community.

One way to evaluate the effectiveness of a radiation safety program is to perform environmental monitoring which can encompass investigating levels of radioisotopes found in surrounding soils, surface/ground water, fauna, flora, and air (i.e. potential sinks where radioisotopes can be deposited).

Previous projects have evaluated radioactive emissions in the stacks from the NIEHS medical-pathological incinerator and the NIEHS chemical waste incinerator, but no measurements have been

made distant from the incinerator building. This project focused on sampling ambient air from a site approximately 50 m away from the incinerator stack to determine if detectable levels of tritium (T) could be measured. The sampler was placed on a location estimated to have the highest potential concentrations based on air modeling exercises. A modified Radeco ACT-100 Tritium & Carbon-14 Gaseous Effluent Sampler was used to collect the samples.

II. BACKGROUND INFORMATION ON TRITIUM

A. Physical Characteristics of Tritium

Since its discovery in 1939 by Alvarez and Cornog (NCRP62, 1979), the radioisotope tritium has been formulated into various devices such as nuclear bombs and self-luminescent instruments (WHO, 1983). Tritium and tritiated molecules have also proven to be versatile tools as tracers in the fields of chemistry, biochemistry, and physiology (Stannard, 1988).

Tritium is the sole radioactive isotope of hydrogen (NCRP62, 1979). Its decay product is ^{3}He formed when tritium releases a negative beta particle from its nucleus. Considered a low energy beta emitter, this isotope releases electrons possessing an average and maximum energy of 5.7 and 18 Kev

respectively (NCRP62, 1979). Tritium has a physical half-life of 12.33 years (relatively long compared to many other tracers) and is found in the following forms: HT - associated with another hydrogen atom (tritium); HTO - a component of a water molecule (tritiated water); and C-T - bound with some organic molecule (ORB - organically bound tritium) (Murphy, 1993). Tritium is most commonly found in the environment as tritiated water (NCRP62, 1979).

Health physics research has found that isotopes of hydrogen are similar but not identical in physical properties (Murphy, 1993) and once absorbed internally, these isotopes are biologically interchangeable (Straume, 1993a). As tritium transmutates to helium, tritiated molecules incorporated with biological material could be chemically and physically altered, potentially causing cellular disruption or cellular death (NCRP63, 1979).

B. Natural Sources

Natural tritium is generated directly in the earth's upper atmosphere by high energy cosmic ray interactions in which nuclear particles (neutrons or protons) collide with oxygen/nitrogen/argon to produce tritium and other molecule(s) (WHO, 1983).

It is also postulated that tritium generated from extraterrestrial sources such as solar flares could migrate into the earth's atmosphere. It is estimated that 1.48E 17 Bq of cosmic-ray derived tritium are produced annually with a global inventory of 2.59E 18 Bq (NCRP62, 1979).

Tritium can also incorporate into water molecules by various processes including photochemical oxidation, exchange reactions, and oxidation by soil organisms (Okada, 1993). Tritium (T) when combined with either protium (^1H) or deuterium (^2H) has the potential of forming inorganic molecules such as HT, DT, T_2, HTO, DTO, T_2O. Tritium and/or deuterium can integrate with carbon atoms through photosynthesis and other biological processes to form organic combinations such as CH_3T, CH_2DT, CHD_2T, CD_3T, CD_2T_2, and CDT_3 (Hill, 1993). Tritium gas (HT or TT) entering the atmosphere oxidizes to form tritiated water (HTO) vapor through a complex process usually requiring catalysts. One suggested mechanism for tritium oxidation involves first the production of TO_2, followed by possible photochemical decomposition to form HTO (NCRP62, 1979).

Researchers theorize various rates for the conversion of tritium to tritiated water. One

researcher postulates that less than 1% of tritium converts to HTO within 24 hours in the atmosphere (Hill, 1993). Other research supports the idea that the primary route of oxidation of HT to HTO occurs by microbial processes in the soil (McFarlane, 1978). As tritiated water vapor is generated in or released to the atmosphere, it can mix with oceans and lakes becoming a surface water component in the hydrologic cycle (Hill, 1993). The earth's crust can also spawn tritium (by ternary fission) when resident lithium atoms are bombarded by neutrons emitted by uranium fissions (Kaufman, 1954).

C. Synthetic Sources

Although tritium has an extremely small natural abundance relative to protium and deuterium, large amounts of tritium (mostly in the form of HTO) have been dispersed through worldwide nuclear weapons usage beginning in 1945 with the majority of detonations being performed between 1954 and 1962 (WHO, 1983). Up to 1979, collected data revealed that 422 nuclear explosions had occurred with a total yield of 217 Megaton (Mt) from fission and 328 Mt from fusion. It is estimated that the tritium yield for fission and fusion denotations is approximately 2.6E 13 Bq Mt^{-1} and 7.4E 17 Bq Mt^{-1} respectively (WHO, 1983). Using these figures, the

yield rate for fusion alone accounts for a total of 2.4E 20 Bq of tritium. This quantity is almost 100 times the estimated global inventory of cosmic ray-generated tritium (2.59E 18 Bq). It is estimated that emissions from weapons testing in conjunction with other synthetic sources have at times elevated tritium biospheric levels to ranges up to a thousand-fold above the estimated pre-nuclear testing levels of tritium (Drobinski, 1965). Fortunately since the advent of weapon testing bans in the early 1960's, tritium concentrations in the environment have been decreasing (Hill, 1993).

Emissions from nuclear electric generating facilities also contribute to the global inventory of tritium. In 1980 it was estimated that nuclear power stations generated 6.3E 14 Bq globally per year when there was an estimated 1.25E 05 MW(e) of power capacity (WHO, 1983). A 1995 global inventory of nuclear power plants indicates that the operating nuclear power plants had 2.78 times the 1980 power capacity (3.42E 05 MW(e)) which by using simple multiplication, gives a rough estimate of the 1995 tritium activity production at 1.75E 15 Bq/yr (Nuclear News, 1995). To bring power plants into perspective, this 1995 rate is only 1% of the estimated annual cosmic-ray generated tritium rate (1.48E 17 Bq/yr).

Tritium sources also include facilities such as separation plants, tritium handling operations, and fuel reprocessing plants (NCRP62, 1979). Some of the physical dynamics causing emissions within tritium-generating facilities are:

1) ternary fission products in fuel elements of reactors;
2) neutron reactions with boron or lithium present for reactivity;
3) heavy water moderated neutron capture in deuterium.

The Savannah River Plant in Aiken, South Carolina historically has been one of the primary production facilities for tritium. Estimated annual tritium releases from one of Savannah River's reactor buildings have been in the order of 8.5E 15 Bq (ten-fold greater than a 1000 Mwe light water reactor) (NCRP62, 1979). Separation facilities at Savannah River have released an average of 1.3E 16 Bq/yr.

Significant levels of elemental hydrogen gas (HT) also continue to be released into the environment due to industrial, commercial and research uses of tritiated compounds (Hill, 1993). Applications involving consumer products such as self-luminescent watch components, methane metal

tritides, tritiated pump oils/solvents, and various types of luminous plastics create continuous supplies of tritium (Okada, 1993).

III. RADIONUCLIDE TRANSPORT

A. General

The transport and fate of radionuclides within a particular environment are influenced by factors which alter holding times, concentrations, and the geographical extent of contamination. Similar to radiologically-stable chemicals, the physical and chemical characteristics of radioactive materials determine how they interact with and cycle through food chains, vegetation, soil, surface waters, etc.

B. Compartments

To help conceptually determine the transport and fate of radionuclides, some researchers conceptualize their movement in terms of compartments (Whicker, 1982). These compartments may be living or non-living and represent the short or long term residence where the isotopes may be found at different points in their cycles. For example when radionuclides are first released from a point source, they will tend to disperse into air or water which is termed by some as the "abiotic media" compartment. If air is the medium, then

forces such as gravitational settling or precipitation begin to operate driving the isotopes into other compartments such as the soil or plants. Herbivores (another compartment) ingesting contaminated plants carry radionuclides to the carnivore component. If displayed in a diagram, the components can be viewed in relational terms, and predictions of radionuclide concentrations can be formulated. The ocean compartment is tritiated water's largest holding station, being predominately transported by air and deposited via vapor exchange (or to a lesser extent by precipitation) (Murphy, 1993). In contrast to HTO, elemental tritium (HT) is quite insoluble in water and a diagram of its distribution among compartments would look quite different.

C. Eddies

Once tritium enters ambient air via incinerator stacks, the initial transport factors dictating its fate will be primarily wind speed/direction and atmospheric stability (Gloyna, 1969). Winds are created primarily by the pressure gradients in the atmosphere and the earth's rotational coriolis effect. Wind quality can be modified by turbulent forces termed eddies which are created by the combined influence of mechanical shearing stress and thermal convectional effects. Mechanical

shearing eddies are generated by the friction between winds and the topography of the land including land features (mountains, valleys) and man-made structures. Building downwash and wake effects can create disturbances in air streams and either concentrate or dilute contaminant concentration. Convection forces are created by temperature variances with their strength dependent on the rate of heating in the lower atmosphere. These two eddy types perturb the average wind velocity parallel to the wind direction (x), in addition to causing turbulence in the horizontal (y) and vertical planes (z) (across the wind direction). This creates gusty conditions and actually facilitates the mixing actions which can dilute contaminants. Layering occurs at different altitudes and is evidenced by situations where both wind speed and wind direction vary drastically within a range of a few hundred feet. Generally, wind velocities increase as altitude increases.

D. Stability

The buoyant stability of the atmosphere depends on the relation between the adiabatic lapse rate (temperature decrease of dry air moving upward) and the surrounding air lapse rate ("actual lapse rate") (Gloyna, 1969). If the adiabatic lapse rate of an air mass is greater than the actual lapse

rate, a continual uprising effect will occur causing unstable atmospheric conditions and mixing/dilution effects on contaminants. If the situation is reversed (adiabatic rate less than actual) then atmosphere is categorized as stable hindering air masses from climbing, creating a capping effect, fumigation plumes (plumes which can carry emission to ground levels) and potential health hazards (Eisenbud, 1987). Other characteristic plume shapes such as looping, coning, fanning, and lofting are created by differing lapse rate combinations between the adiabatic and the actual. Focusing on a smaller scale, it is conceptually important to remember that molecular diffusion itself will also tend to spread out the contaminates but usually to a minor extent.

E. Stack Determinants

The following factors summarize the primary determinants influencing the fate of chemical or radiological stack emissions (Gloyna, 1969):

1) wind direction and wind speed;
2) atmospheric stability;
3) types of gases or particulates involved;
4) temperature of emissions relative to surrounding air;

5) density of the plume;
6) initial velocity;
7) chemical properties especially of the particle surfaces.

IV. BACKGROUND TRITIUM LEVELS

A. General

As mentioned, natural sources, nuclear detonations, and to a smaller extent nuclear power plants are responsible for global tritium levels. Most of these releases having occurred in the northern hemisphere (NCRP62, 1979). Studies on fallout reveal that tritium has dispersed and incorporated itself into all hydrogen-containing materials in the biosphere (Bogen, 1976). Most of tritium in the environment is found in the oxidized form (HTO) and resembles water in its mobility (Hill, 1993).

Research up to 1977 revealed that an estimated 1.0 kg of tritium gas (HT or TT) was fairly evenly distributed throughout the atmosphere (troposphere and stratosphere). The same research concluded that an estimated 5.1 kg of HTO was located in the stratosphere and an additional 0.2 kg was distributed in the troposphere (Mason, 1979).

Whether taken internally into organisms or dispersed through the environment, tritium as either HT or HTO mimics the activity of its non-radioactive sister molecules because the three hydrogen isotopes are chemically similar (Murphy 1993).

B. Deposition

HTO appears to be transferred from the atmosphere to earth's surface predominately by precipitation but it can also be transferred by direct vapor exchange (NRCP62, 1979) (Kline, 1974). The efficiency of this scrubbing or washout of tritium by rainfall appears to be dependent on the type of storm and the size of the droplet. The estimated half-life of tritiated water in the atmosphere ranges from 21 to 41 days (Murphy, 1993). The deposition rate ranges from 0.4 to 0.8 cm/sec, and the rate tends to be higher over the oceans than over land (Murphy, 1993). In contrast to HTO's residence time, HT's half-life in the atmosphere is estimated to be 6.5 years.

One study investigated the specific tritium activity of rain (ground level) at different points away from a stack, which was emitting tritium in the form of tritiated water (Chamberlain, 1964). The activity peaked at a distance from the stack

which was approximately the same distance as the stack height itself, though this distance was dependent on wind speed.

C. Recorded Background Levels

As mentioned previously, past nuclear detonations have added significantly to the global inventory of tritium. Through various processes including rain washout, vapor exchange, and tritium decay the levels have been dropping over the past 30 years since bans began on nuclear testing. The pre-nuclear wine levels of 3-30 pCi/L may reflect previous air concentrations but it remains to be seen how far tritium levels will decrease (Drobinski, 1965). Tritium data over the last 15 years indicate that the tritium concentration in precipitation and drinking water are approaching 100 pCi/l. Although the future for US nuclear power plants does not look promising at this point, other nations are continuing to develop and build new plants.

The following table presents data related to background levels of tritium in the environment. In the column recording "tritium level", the first number represents the value as listed in the reference. The italicized number below is a calculated value translating a precipitation or surface water value into an estimated equivalent air vapor concentration. The assumption is made that the air temperature is approximately 70 degrees F and the relative humidity is 70%.

Table 1 - Background Tritium Levels

Date	Form	Location	Tritium level	reference
Pre-nuclear testing.	Stratospheric water	World-wide	.03 pCi/cm^3 *.42 pCi m^{-3}*	Budnitz, 1974
Post-nuclear testing, 1960 testing.	Stratospheric water	World-wide	2E4 pCi/cm^3 *2.8E5 pCi m^{-3}*	Budnitz, 1974
1961	Surface/tap water	Northeast US	280 pCi/l *3.92 pCi m^{-3}*	Bogen, 1979
1962	Surface/tap water	Northeast US	1000 pCi/l *14 pCi m^{-3}*	Bogen, 1979
1963	Surface/tap water	Northeast US	1100 pCi/l *15.4 pCi m^{-3}*	Bogen, 1979
1964	Surface/tap water	Northeast US	1100 pCi/l *15.4 pCi m^{-3}*	Bogen, 1979
1965	Surface/tap water	Northeast US	1200 pCi/l *16.8 pCi m^{-3}*	Bogen, 1979
1966	Surface/tap water	Northeast US	1050 pCi/l *14.7 pCi m^{-3}*	Bogen, 1979
1967	Surface/tap water	Northeast US	1025 pCi/l *14.35 pCi m^{-3}*	Bogen, 1979

Date	Form	Location	Tritium level	reference
1968	Surface/tap water	Northeast US	900 pCi/l *12.6 pCi m^{-3}*	Bogen, 1979
1969	Surface/tap water	Northeast US	800 pCi/l *11.2 pCi m^{-3}*	Bogen, 1979
1970	Surface/tap water	Northeast US	700 pCi/l *9.8 pCi m^{-3}*	Bogen, 1979
1971	Surface/tap water	Northeast US	400 pCi/l *5.6 pCi m^{-3}*	Bogen, 1979
1968,	Stratospheric water vapor	world-wide	80 T.U. or 3.62 pCi m^{-3}	Budnitz, 1974
1971	Precipitation	New York City	340 pCi/l *4.76 pCi m^{-3}*	Bogen, 1979
1972 -	Precipitation	New York City	210 pCi/l *2.94 pCi m^{-3}*	Bogen, 1979
1970	Tap water	New York City	480 pCi/l *6.72 pCi m^{-3}*	Bogen, 1979
1971	Tap water	New York City	350 pCi/l *4.9 pCi m^{-3}*	Bogen, 1979
1972	Tap water	New York City	270 pCi/l *3.78 pCi m^{-3}*	Bogen, 1979
1973	Tap water	New York City	230 pCi/l *3.22 pCi m^{-3}*	Bogen, 1979
1973	Precipitation	New York City	200 pCi/l *2.8 pCi m^{-3}*	Bogen, 1979
1974	Tap water	New York City	190 pCi/l *2.66 pCi m^{-3}*	Bogen, 1979
1975	Tap water	New York City	190 pCi/l *2.66 pCi m^{-3}*	Bogen, 1979
1976	Tap water	New York City	180 pCi/l *2.52 pCi m^{-3}*	Bogen, 1979
1977	Tap water	New York City	190 pCi/l *2.66 pCi m^{-3}*	Bogen, 1979

Date	Form	Location	Tritium level	reference
1978	Tap water	New York City	200 pCi/l *2.8 pCi m^{-3}*	Bogen, 1979
July-Sept 1991	Precipitation	Wilmington	100 pCi/l *1.4 pCi m^{-3}*	EPA, 1991
July-Sept 1991	Ocean water	Southport	200 pCi/l *2.8 pCi m^{-3}*	EPA, 1991
Jan-March 1992	Precipitation	Charlotte	200 pCi/l *2.8 pCi m^{-3}*	EPA, 1992a
Oct-Dec 1993	Precipitation	Wilmington	100 pCi/l *1.4 pCi m^{-3}*	EPA, 1993
Oct-Dec 1994	Precipitation	Wilmington	100 pCi/l *1.4 pCi m^{-3}*	EPA, 1994
Apr-June 1995	Precipitation	Charlotte	100 pCi/l *1.4 pCi m^{-3}*	EPA, 1995a

1) At 70 degrees F and 70% humidity, a cubic meter of air at 1 Atmosphere contains approximately 14 grams of water vapor (Hammond).
2) One Tritium Unit (TU) corresponds to 3.23E-3 pCi/cm^3 of water (Budnitz, 1974)

V. TRITIUM EXPOSURE

A. Tritium Internalization

External exposure to tritium is not a real concern because the low-energy emissions are not able to penetrate the skin, but once internalized, tritium's beta emissions can cause cellular damage. If tritium is present in the environment (especially as HTO), it can potentially enter the body through inhalation, ingestion, or absorption through skin. When a molecule of HTO is internalized, it functions metabolically as water and either migrates freely through the body or chemically exchanges with other tissue-bound hydrogen. Generally, HTO does not seem to concentrate to any great measure in any particular organ(s) which distinguishes it from some radionuclides of concern (ex. - iodine & strontium) (Hill, 1993). The International Commission on Radiological Protection (ICRP) recommends that when calculating tritium dosages, one should assume that internalized HTO is completely and instantaneously absorbed, mixes rapidly with total body water, and that concentrations in sweat, sputum, urine, blood, insensible perspiration, and exhaled water vapor are identical (Hill, 1993). In contrast, HT (non-oxidized tritium) is relatively inert biologically, and usually has a very low uptake into body fluids.

B. Biological Half-life

Duration of exposure, distance, and shielding are three key components of radiological exposures to external sources. When dealing with internalized tritium, the time of exposure is related to the biological half-life, the time it takes half of the tritiated material to be eliminated from the body. Research on tritium biological half-lives is not totally consistent, but it appears that there are possibly two to three separate and distinct biological half-lives representing different types of biological molecules that tritium can become incorporated with. The following summaries present perspectives on the search to understand tritium's interaction inside the body:

1) It is thought that there are three internal components with distinct biological half-lives. One perspective is that these three components represent tritium associated with body free-water, tissue free-water, and tissue-combined hydrogen (Stannard, 1988). A more biochemical viewpoint suggests that the three components are body-water tritium, organically-bound exchangeable tritium, and organically-bound non-exchangeable tritium. Exchangeable tritium refers to tritium binding with nitrogen, phosphorus, oxygen, or

sulfur. The non-exchangeable tritium is bound to carbon.

2) Researchers have found different biological half-lives, some with wide ranges (Hill, 1993). Looking at 15 studies, it appears that the first component averages around 8.3 days with a range of 6 - 12 days. The second component averages around 30 days but more variation has been observed than for the first component (range 10 - 226 days). Data for the third component are difficult to harmonize but the numbers seem to revolve around 300 days (range 139-550 days).

Once internalized, regardless of the route of entry, HTO can spread through the body by circulation or diffusion making entry into cells by crossing plasma membranes. Once inside the cell, the beta emissions given off during decay can potentially disrupt activities. Also, molecules that have incorporated tritium into their structure can become disrupted when the tritium atom transmutates to the daughter helium atom (Hill, 1993).

Due to the fact that hydrogen is such a basic building block of biological molecules, tritium in the HTO molecule could potentially become

incorporated into a variety of cellular components. Those tissues which have a higher contact with internalized HTO due to location and/or function are more likely to be exposed to tritium emissions and are also more likely to experience tritium transfers. When exchanges involving carbon-hydrogen bonds (C-H) occur, tritium can integrate more intimately with tissues due to carbon's strong attraction for electrons. Tritium bound in this form is termed nonexchangeable bound tritium fraction and is usually removed only by enzymatic breakdown. Falling into this category is tritium bound to structural proteins, collagen, and nerve-cell phospholipids which are all characterized by having a relatively slow turnover rate. Fewer of these types of molecules tend to be tagged by tritium because of the slow metabolic rates but when tritium is bound it is held for longer periods of time. Some researchers feel that these types of tagged molecules are associated with the biological half-life fraction which averages around 300 days (Hill, 1993).

In contrast to the nonexchangeable bound tritium fraction, the major portion of internalized tritium consists of tritiated organic and inorganic compounds which are characterized by having a similar metabolism and/or distribution as HTO,

experiencing a higher turnover rate, and by being removed more expediently from the body (Hill, 1993). This group of tagged molecules exchange more readily with hydrogen found in the body's water pool and are referred to as the exchangeable bound tritium fraction. Some research suggests that this main component of internalized tritium has a half-life around 8.3 days.

C. Tritium Ingestion

Tritium, tritiated water, and tritiated organic compounds in contaminated food or liquids can enter the body by ingestion and be passed down the alimentary tract. Once in the intestines, tritiated water is almost entirely absorbed, and studies of tritium levels in venous blood indicate that absorption occurs rapidly. The blood-borne tritium is then transported throughout the body and can be found in varying concentrations in organs, tissues, and fluids. Although tritium in the elemental form (HT) is absorbed poorly, conversion to HTO has been shown to occur in the intestinal tract by oxidizing bacteria (NCRP62, 1979). Tritiated organic compounds can also pass across the intestinal lining and be transported throughout the body. Since many NIEHS researchers use tritium as tritiated thymidine, it is interesting to note that research suggests only 1/8 of the tritiated

thymidine ingested survives catabolism intact to cross the gut as thymidine (NCRP63, 1979).

D. Tritium Inhalation

Inhalation studies reveal that elemental tritium (HT or TT) is much less likely to be absorbed through the lungs than tritiated water, the relative inhalation hazard (dose) from HT being approximately 1/1000 that from the same concentration of HTO (Sheehan, 1975). The HT (or TT) that is absorbed by the lungs (approximately .004%) becomes dissolved in body fluids and is then converted into HTO by bacteria in the gastrointestinal tract (Hill, 1993) (Stannard, 1988). This absorption/conversion process is considered to produce one half of the total HT dose, the other half coming from the tritium irradiating the lungs directly.

In contrast to elemental tritium, blood analyses show that nearly all of the tritium oxide inhaled (98-99%) is delivered to the bloodstream within seconds and eventually released via kidneys in urine (Stannard, 1988) (NCRP63, 1979). Little is understood about the inhalation dose of other forms of tritiated molecules (ex. CH_3T).

E. Tritium Skin Absorption

As previously mentioned, tritium emissions are not considered an external threat to the human body since the maximum range of the beta particles in tissues is only around 6 um, while the depth of cells in skin is typically greater than 30um (Okada, 1993). Even the eye is not significantly threatened by tritium emissions because radiosensitive tissues of the eye are minimally at a 3mm depth. (Hill, 1993) The only real potential external problem with tritium is the release of bremsstrahlung energies which can occur when tritium levels are very high.

Although the skin adequately guards the body from the external effects of tritium radiation, it offers little protection from tritium absorption when tritium is in the form of tritium oxide. Research indicates that HTO skin absorption can be significant ranging from 50% - 99% of pulmonary absorption (Hill, 1993) (Stannard, 1988). This is somewhat surprising considering that the lungs have fifty times more surface area than the skin surface. One suggested explanation for this phenomena is that the fluids which bath the lungs could be diluting the tritium and decreasing the specific activity. It has been noted that as physical activity elevates in an individual, HTO

lung absorption increases to a point where during typical work duties the inhalation dose doubles (compared to resting baseline). In contrast to the increased respiratory uptake due to activity, the skin absorption rate remains stable although research indicates that tritium uptake via skin can be affected by temperature. Since individuals can potentially absorb significant amounts of HTO through the skin, the ICRP (1979-1982) has suggested that measurements of tritium inhalation doses (via lung only) be multiplied by 1.5 to take into account this additional dose through the integumentary system (Hill, 1993).

In contrast to the HTO's absorption across the skin (or lungs), elemental tritium (HT) is not significantly absorbed across the skin. For this reason, HT does not present an external or internal radiological threat unless an individual is exposed to relatively high concentrations.

VI. BIOLOGICAL EFFECTS OF TRITIUM EXPOSURE

A. Indicators of Biological Effectiveness

To better understand the potential health hazards due to tritium exposure, one must consider various chemical and physical qualities of this isotope. First, tritium has a fairly long physical half-life

(12.3 years) which would indicate that the specific activity is relatively low. Second, as previously mentioned, tritium in the form of HTO has a relatively short biological half-life (8.3 days) in the human body and is eliminated effectively by the kidneys. Third, internalized HTO's characteristic of disseminating fairly evenly throughout the body precludes any loading up on specific tissues. Fourth, as previously mentioned, tritium's beta emissions have relatively low energy. These four features suggests that relative to doses from most other nuclides, internalized tritium doses to any particular organ or tissue is relatively low.

Another characteristic of radioactive emissions is the Linear Energy Transfer (LET) which refers to the quantity of energy imparted to biological material per linear measurement. Low LETs are associated with gamma rays, x-rays, and beta rays (including tritium) while high LETs are associated with neutrons and alpha particles. Generally, the higher the energy transfer, the more effective the radiation is in damaging the cell or organism. Some data focusing on tritium exposures has suggested that this isotope has a higher than expected ability to do biological damage despite its low-energy emissions (Stannard, 1988).

A tool to help understand the health implications of tritium emissions is the Relative Biological Effectiveness (RBE) which is the ratio of the absorbed dose of specific energy (usually 250-kVp x-rays) to the equivalent absorbed dose of any other ionizing radiation which produces the same biological effect.

$$RBE_{HTO} = \frac{\text{Dose of Reference Radiation Causing Effect}}{\text{(Dose of Tritium Oxide Causing Same Effect)}}$$

This expression is used in radiobiological work and risk assessment, and is an attempt to normalize the effects of specific isotopes because it has been determined that the same dose from two different types of ionizing radiation may not cause the same damage.

RBE varies as a function of dose, dose rate, energy of the radiation, the type and degree of biological damage, and the nature of tissue or organism under consideration (NCRP63, 1979) (Hill, 1993). Estimates for tritium's RBE range from less than 1.0 to 2.0.

Similar to the RBE is the quality factor (Q) which is a value recommended by the ICRP for use in setting radiation protection standards. This term is a conservative upper limit of the RBE for the

most important effect due to radiation (i.e. - cancer).

RBE's and Q factors are related to LET values. It has been suggested that the RBE for tritium be set greater than 1 and that Q be increased from its present value of 1 to 2 but there remains much controversy concerning this point (Stannard, 1988).

B. Tritium Dose

"Absorbed dose" is the measurement of energy (joule) deposited into unit of mass (kg) by ionizing radiation and is measured either in terms of *rad* or *gray*. Related to the absorbed dose is another concept termed "equivalent dose" which is used to represent how effectively specific types of radiation cause damage to tissues. The equivalent dose is measured in terms of *rem* or *sievert*. Tissues absorbing some dose of ionizing radiation can be potentially damaged by chemical changes due to phenomena such as ionizations, excitations, dissociations, and from beta particles providing the activation energy to drive chemical reactions (radiation effect) (Hill, 1993). The real concern from tritium focuses on internal doses. The mean range of tritium's beta track being less than 0.6 um is even short compared to the size of many

cells, although the size and shape of cells varies significantly (Okada, 1993).

The actual dose from radionuclides is a function of many factors such as the type of emissions (alpha, beta, gamma), energy level of those emissions (in terms of electron volts (ev), and amount of radionuclide in the body (activity (ex. - uCi) (Hill, 1993). Other determinants include densities of the ionizations (specific activity - ex. uCi/kg), localization effect, in addition to the rates of the uptake, deposition, and elimination of the radioactive material (Hill, 1993). The uptake, deposition, and elimination will depend on the chemical form, solubility and the presence of a carrier.

Cells exposed to ionizing radiation may absorb some or all of the energy emitted. That portion of the energy actually absorbed for a given mass of tissue is appropriately termed the "absorbed dose" and is used as an indicator of the probability of stochastic effects (ex. cancer, mutations) occurring after irradiation. When tritium enters into cells, the majority of the emitted energy may be absorbed by the surrounding intracellular water and associated solutes while the balance of energy may be deposited into organelles such as

mitochondria and nuclei. When tritium is inhaled, some decay can occur in the pulmonary space with only a portion of the decay energy being absorbed into respiratory tract cells. The balance of energy from the emitted beta particles is transmitted to either the surrounding air in the lungs or bronchioles, or for particle-bound tritium, the energy can be transferred to the particle itself (self-absorption).

C. Morbidity/Mortality

Regardless of tritium's route of entry or specific interactions with biological molecules, the fact is that relatively little is known about the effects of tritium on human health. Most research has been centered on animal and in vitro studies, with most data being drawn from acute exposures. The following phenomena have been correlated with these acute tritium exposures: a) carcinogenesis, b) fetus malformation, c) mutagenesis, d) death, and e) hematopoietic stem cell death (Okado, 1993).

D. Cancer

One of the potential dangers of tritium exposure is that cancer could be initiated by the modification of an oncogene or a suppresser gene. These modifications could occur due to beta particle

emissions or by transmutation (^{3}H becoming ^{3}He). In fact, radiation dose is probably the single most important risk factor for radiation-induced cancer. Depending on the dose received, estimates on the range of lifetime excess cancer-mortality vary from zero up to approximately 20% (at near lethal doses) (Straume, 1993b). Dose rate plays an important role in excess cancer mortality. This could be especially true with lower LET radiation such as tritium because research with gamma rays and x-rays reveals that some higher cancer rates correlate with higher dose rates. Specific cancers such as leukemia seem dose-rate sensitive while breast cancers are rather independent of dose-rates and are more related to total dose. Radiation quality is a third factor which affects risk assessments (Straume, 1993b).

E. Mutations

Personnel in facilities like the NIEHS are not likely to suffer consequences from acute tritium exposures but long term effects are possible due to the prolific use of tritium in physiology experiments. For example, tritiated thymidine can become incorporated into DNA and potentially generate chemical transmutations, nuclear recoils, and charge-producing positive ions (Cronkite, 1973).

Tritiated thymidine, a popular tool with researchers studying metabolic activities, can indicate mitotic activity by incorporating with newly synthesized DNA. Research has shown that when absorbed into the body, 40 to 60% of this DNA building block is assimilated into chromosomes. Tritiated thymidine incorporates more often in those cells experiencing higher division rates such as the hematopoetic tissues in adults. And similar to the dangers mentioned with cancer formation, ionization caused by beta emissions and the transmutations from tritiated thymidine (or tritium in other forms) could possibly disrupt the structure and function of genetic codes. As transmutations occur, and DNA-incorporated hydrogen converts to helium, the bond with adjacent carbons becomes weakened and the outcome can be free helium and unstable carbon ions. These carbon ions can cause molecular alterations in DNA leading to single strand breaks and interstrand cross-links. Comparing beta emissions and transmutations, the NCRP's perspective is that beta emissions are more disruptive (NCRP63, 1979).

F. Fatalities

In Switzerland, there are two documented case studies of tritium related fatalities involving two radioluminizers who worked with one hundred to

several thousand curies of tritium for three to six years. Death was apparently due to destruction of hematopoietic tissue. A drop in their red cell count was dramatic while white cells appeared to be unaffected. Estimates for whole-body dose were approximately 290 rem. One researcher studying these fatalities estimated that 10% to 20% of body tritium was organically bound (Stannard, 1988).

G. Developmental Effects

Most cells in the fetus are actively dividing during developmental stages and the first trimester seems to be the most vulnerable period. If tritiated thymidine is administered to the fetus, all the cells become labeled because of the increase in mitosis. Exposure to tritiated water causes a more general dose in that the water generally disperses to all tissues (NCRP63, 1979).

VII. TRITIUM USAGE AT NIEHS

A. General Use of Isotope

The NIEHS is primarily oriented towards basic research, investigating the impacts of chemical and physical agents on human health. Research has traditionally involved animal and cell models but new initiatives integrate clinical studies.

Radioisotopes are typically used at the NIEHS for tracking biochemical routes, and studying the anatomical and physiological effects that environmental agents have on cells or living organisms. When a tagged molecule is introduced into cells or animals, a researcher can study transport of specific molecules and any potential target organs that those molecules could impact. Also, other research projects may attempt to discover what daughter metabolites are produced or how molecules (or daughter molecules) are assimilated/eliminated. Tagged molecules such as tritiated thymidine are commonly used in monitoring mitotic activity. As new DNA is synthesized during active cell division, nucleotides containing thymidine will be incorporated into the new chromosomes and the activity can be measured through scintillation counting.

B. Exposure to Radioisotopes

The important routes of exposure to tritium are inhalation, skin absorption, and ingestion. To minimize exposure to researchers from ingestion, no eating or drinking is allowed in the laboratories. To minimize skin absorption and inhalation, NIEHS personnel wear gloves and are strongly encouraged to utilize a laboratory hood when handling solutions containing relatively high levels of

activity. If volatile radioactive compounds are involved, the use of a hood may be required.

The NIEHS researchers submit spent radioactive materials to the Health and Safety Branch for handling and disposal. The bulk of this material is usually treated on-site in either the hazardous waste or medical-pathological incinerator. According to 1996 records, 742.5 mCi of tritium-containing compounds were incinerated on-site.

Exposure to tritium from the NIEHS incinerator emissions is the main focus of this project. During the incineration process, radioisotopes are exposed to very high temperatures (above 1880 degrees F) in the secondary chamber which would vaporize any tritiated water. Other forms of tritium such as tritiated-organic compounds (ex. tritiated thymidine) are essentially oxidized to HTO and vaporized by the heat.

Potential HTO exposures to the NIEHS staff from the NIEHS incinerators are likely to be small due to the height of the stacks (relative to the nearby terrain), the low levels of materials burned (< 1/10 of allowable), and the location of the stack relative to the surrounding buildings.

The NIEHS incinerator stacks which emit radioisotopes extend to an altitude of 376 feet (above sea level), higher than any building on the South Campus. The incinerator building's base is on one of the higher points (elevation - 338 feet). The boiler building (Building 105) adjacent to the incinerator has a rooftop elevation of approximately 366 feet. Air dispersion modeling indicates that highest potential exposure to radioisotope concentrations from incinerator emissions exists for a person standing on the rooftop of Building 105. Staff only rarely work on top of that building.

The NIEHS limits the tritium emitted from the incinerator stack to a concentration less than 2.0E -07 uCi/ml averaged over a 24 hour period. Since the total flow of gas emitted from the incinerator has already been determined (~5500 ACFM*), it was possible to ensure compliance to the concentration limit by simply limiting the amount of tritium loaded into the incinerator to a maximum of 47 mCi over a 24-hour period (approximately 226,000 m^3/24 hours) (see Appendix B). At times the actual concentration in the stack gas may exceed the limit but when averaged over the 24 hour

*Actual Cubic Feet per Minute

period, it would not exceed the concentration threshold of 2E -07 uCi/ml.

A diagram of the buildings on the South Campus indicates that the incinerator building is part of a complex set off from the main research building (Building 101). The majority of the NIEHS personnel are stationed in Building 101, which is located approximately 2000 feet northwest from the incinerator building (Building 106 - see Figure 1 and Figure 2). Building 101 consists of four floors in the research modules and has a rooftop elevation of approximately 320 feet, with most air intakes located on the sides of the building just below the rooftop.

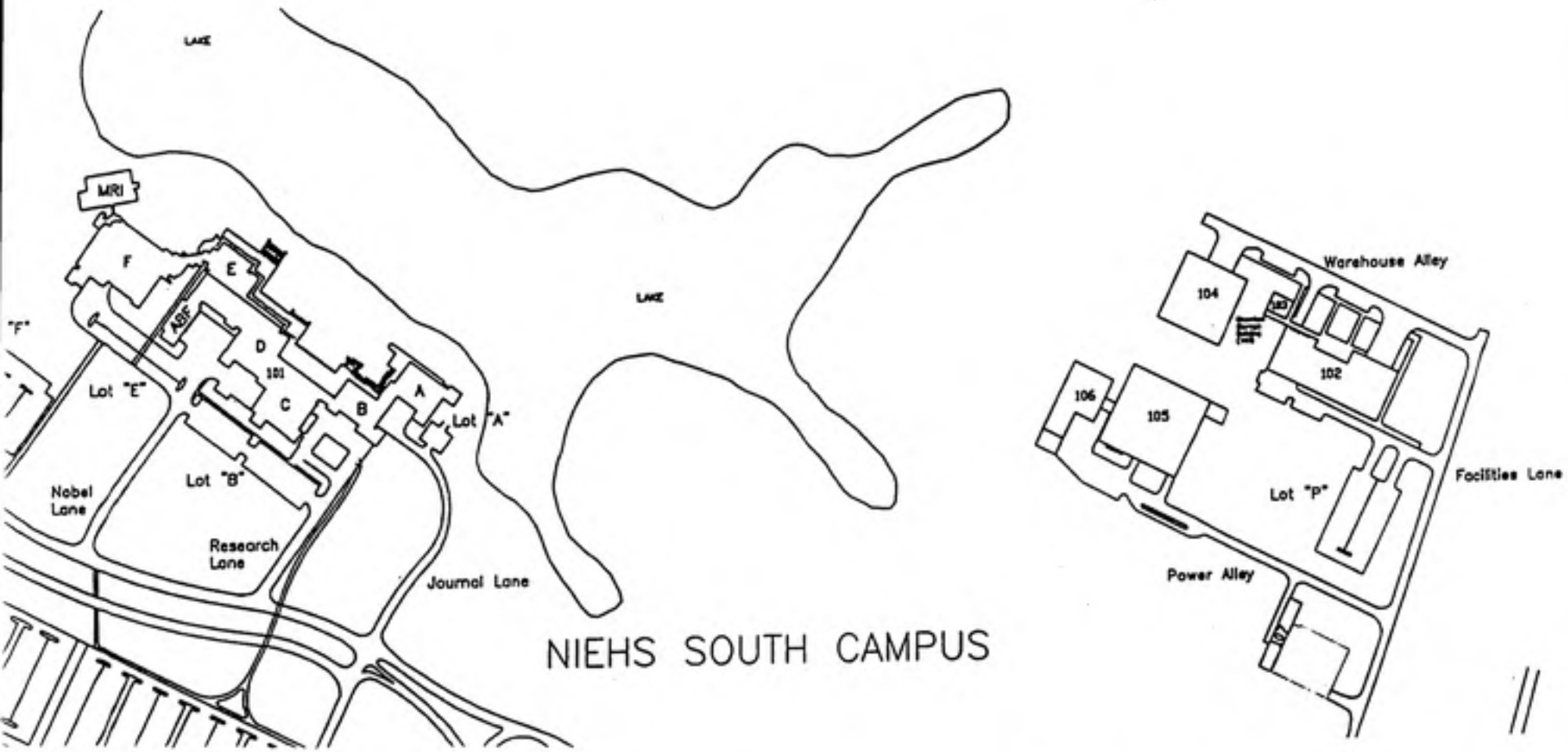

Figure 1 - NIEHS South Campus

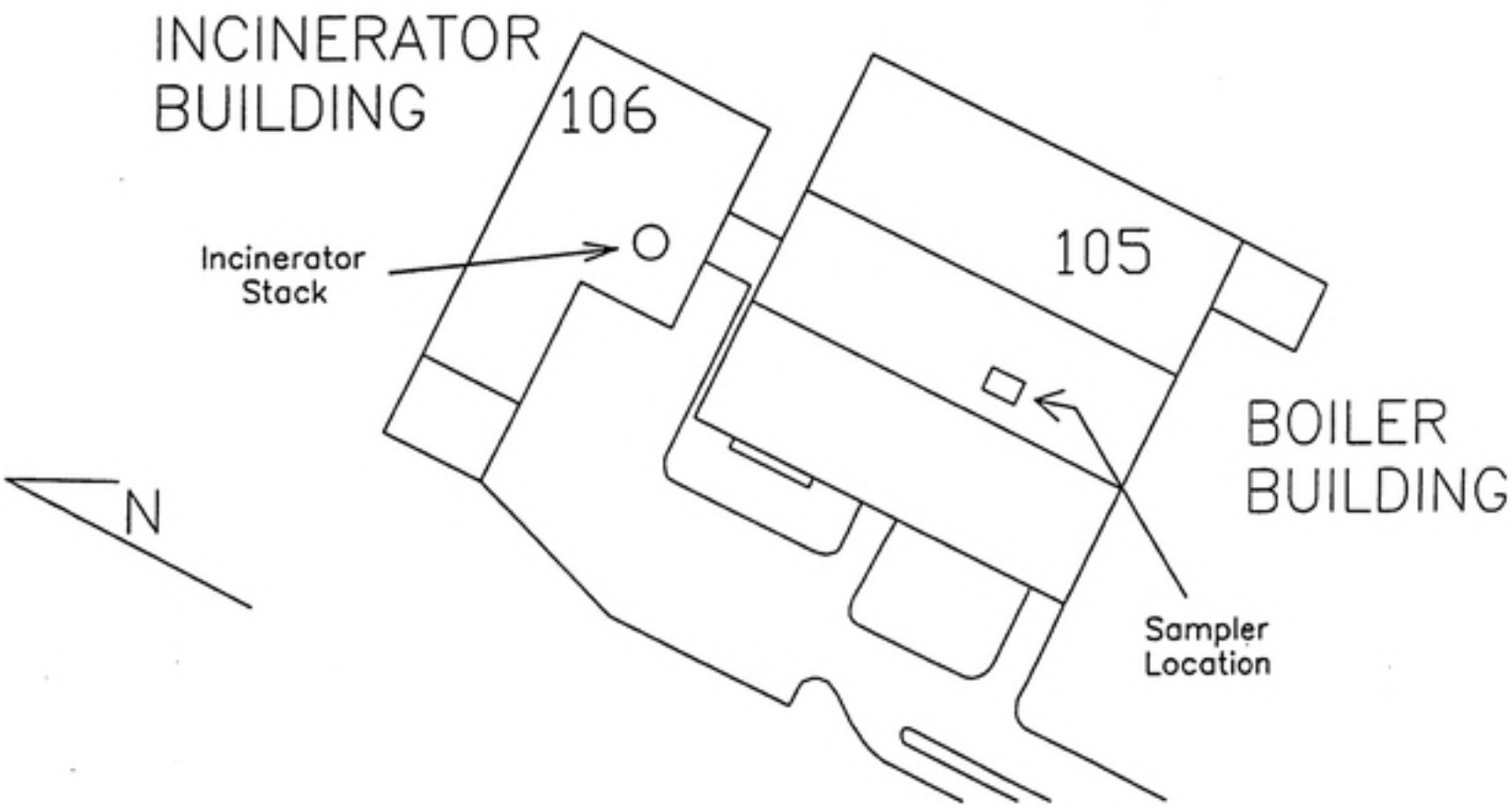

Figure 2 - Buildings 105 & 106

III. AIR SAMPLING TECHNIQUES

A. Air Sampling Equipment

Current methods of sampling and measuring tritium have not changed significantly in the last 10 years (Wood, 1993). Tritium samplers can be separated into two general types, real-time samplers and discrete samplers. Real-time samplers incorporate a measuring device which can rapidly register tritium concentrations. Discrete samplers draw in a volume of air or components of air (i.e. - water vapor) with a subsequent processing/analysis of the captured radioisotope carried out in the laboratory.

Two common real-time samplers are ionization chambers and proportional counters (Budnitz, 1973). Ionization chambers operate by measuring very small currents from ions generated by emissions passing through air. Ionization chambers are relatively sensitive and can detect tritium in any form because the device is not dependent on the chemical nature of the atoms or tagged molecules although other non-tritium isotopes present can cause interference. Proportional counters differ from ionization chambers in that they count pulses instead of measuring current and can discriminate between some isotopes. Proportional counters

achieve lower minimum detectable concentrations than ionization chambers which is reflected by systems sensitive down to 0.1 pCi/cm^3 (ionization chambers - 1 pCi/cm^3) (Sheehan, 1975).

B. Discrete Samplers

Tritium collection in air can be performed by either a passive or active sampler. Passive samplers depend on diffusion and natural air currents for direct contact with contaminants. Active samplers use a pump to draw a volume of air through the instrument.

Passive tritium samplers can take many forms. Some passive tritium samplers operate by exposing air to a cold surface (termed a cold finger or freeze trap) and collecting the condensate. The condensate formed contains the HTO present in the water vapor, but will not contain significant levels of HT. Other passive samplers collect by natural diffusion and allow the tritium-in-air to have contact with water or other sorbent (Wood, 1993). Passive samplers are especially useful in remote areas where electric power is not accessible. Another advantage with passive samplers is that the HTO collected does not have to be extracted but is ready to mix directly with scintillation cocktails. One disadvantage is that

the actual air concentration of contaminants is difficult to determine since there is no pump/flowmeter involved in the sampling process.

Active type samplers usually function using one of the three following processes (NCRP, 1976):

1) bubbling air through non-tritiated water or some other appropriate solvent;
2) passing air through a desiccant such as silica gel, drierite (Calcium Sulfate) or a molecular sieve;
3) freezing or condensing the water.

Bubblers are frequently used to collect contaminants from air samples. Air is drawn via pump through non-tritiated water which collects HTO with a 90-98% efficiency but is not very effective for absorbing tritium gas (>.01%) (NCRP47, 1976). Sampling for HT or tritiated organics requires the HTO be oxidized, typically using a catalytic furnace containing metals such as palladium and/or platinum. Bubblers can be used in tandem to increase efficiency with an air stream initially passing through one bubbler collecting the HTO, a catalytic furnace converting other tritiated compounds into HTO, and then a second bubbler collecting this newly generated HTO (Sheehan, 1975). Ethylene glycol is also used to collect HTO

(99.4%) and no correction is required for evaporation.

Bubblers are convenient since the sample is directly collected but the sample is diluted decreasing the sensitivity of the analysis. One bubbler system was able to detect down to approximately 0.01 pCi/cm^3 (Sheehan, 1975).

Sampling systems can also use a variety of desiccants to collect tritium. These systems can be engineered to collect only HTO or they can use catalytic furnaces to also collect other tritiated molecules. The three main types of desiccants used in tritium samplers are silica gels, drierite, and molecular sieves. As with the bubbler systems air is drawn through desiccant via a pump and a flowmeter is typically incorporated for calculating the total volume of air sampled. The HTO once collected is then either extracted or displaced for analysis in a scintillation counter. Extraction involves using heat to drive moisture from desiccant and collecting it by distillation. Displacement is performed by adding water to the desiccant and allowing absorbed water to be displaced by the additional water.

The advantages of using desiccants are that they require low maintenance and can be left out in the field for long periods of time with very little oversight. They can effectively remove moisture (approaching 100%), and if the volume of air drawn through the desiccant is measured, the average concentration of the contaminant can be calculated. One disadvantage of using the displacement method is that the addition of water will dilute the sample and decrease sensitivity. One manufacturer of a desiccant sampling system (using drierite) claims that its system can potentially measure down to 1E -03 pCi/cm^3 (1000 pCi/m^3) (SAIC, 1987).

C. Placement of Sampler

The location for environmental air samplers is dependent on the following variables:

1) direction and distance of potential receptors from the source, especially high-density receptor areas such as schools, apartment building, etc.;
2) direction and speed of the prevailing winds along with the stability of the atmosphere;
3) the terrain of the surrounding area including wake effects from surrounding buildings;
4) the height of the emission source;
5) the stack gas velocity and temperature;

6) the nature of the emissions such as particulate size, density of the gas, etc..

As mentioned previously, the main research building (Building 101) houses most of the NIEHS South Campus personnel and is the closest, high-density location of potential human receptors. Placement of an air sampler in the direction of Building 101 (northwest) seems appropriate but the surrounding terrain on the northwest side of the incinerator building drops off and is at a much lower elevation than the stack tip.

IX. NIEHS AIR MONITORING PROJECT

A. Previous Emission Studies

In the early 1980's, a study was performed that focused on the incineration of radioactive wastes at the NIEHS (Parker, 1983). The study had the following goals:

1) to evaluate a particular type of system to monitor tritium and C-14 emissions;
2) to determine the incinerators ability to incinerate tritiated and C-14 compounds;
3) to compare the amounts of these isotopes as emissions to the amount of these isotopes incinerated.

The sampling train used for this project collected gases and particulates from a sampling port in the incinerator stack. Tritium as HTO was absorbed in an impinger filled with silica gel. The tritium was desorbed by diluting the exposed silica gel with distilled water. Allowing one hour for desorption, aliquots of 1 ml were removed and added to 15 ml of scintillation cocktail.

Analysis of samples revealed that the monitoring efficiencies for controlled burns (when spiked waste was loaded) were relatively low ranging from 50% to 85%. Also, monitoring efficiencies for normal burns (waste submitted by NIEHS researchers) were very low, ranging from 13% to 56%. It was proposed that the low results from the normal burns were caused by researchers overestimating the activity of the material submitted. It was also discovered that less than 0.1% of the tritium incinerated was found in particulates collected from the stack gases.

This 1983 study provided helpful information by observing that only insignificant amounts of tritium incinerated are emitted as particulates and that almost all of the released tritium is in the gaseous form. The sampler used in this present study is designed for collecting tritium in the

gaseous form and would not collect tritiated compounds on particulates. Also, it is helpful to know that concentration calculations of emitted radioisotope may be overestimated when based on researchers' reports.

Another emission project involving tritium followed the 1983 study. This study (Knapp, 1984) investigated incinerator ash and discovered that only a very small percentage (approximately .0014%) of tritium remained after a burn. Also, it was observed that no detectable tritium could be found in the refractory of the incinerator. This indicates that essentially all the tritium incinerated is discharged through stack gas emissions. Also, the profile of the incinerator gases sampled suggested that most of the tritium was oxidized fully to HTO.

B. Field Methods

As mentioned the air sampling for this project was performed using a Radeco Model ACT-100 Tritium/Carbon-14 Gaseous Effluent Sampler (see Figure 3). This device utilizes previously established methods to trap tritium and carbon-14 in separate cartridges. The sampler draws gases at a controlled rate through an inlet port and into a stainless-steel furnace lined with catalysts

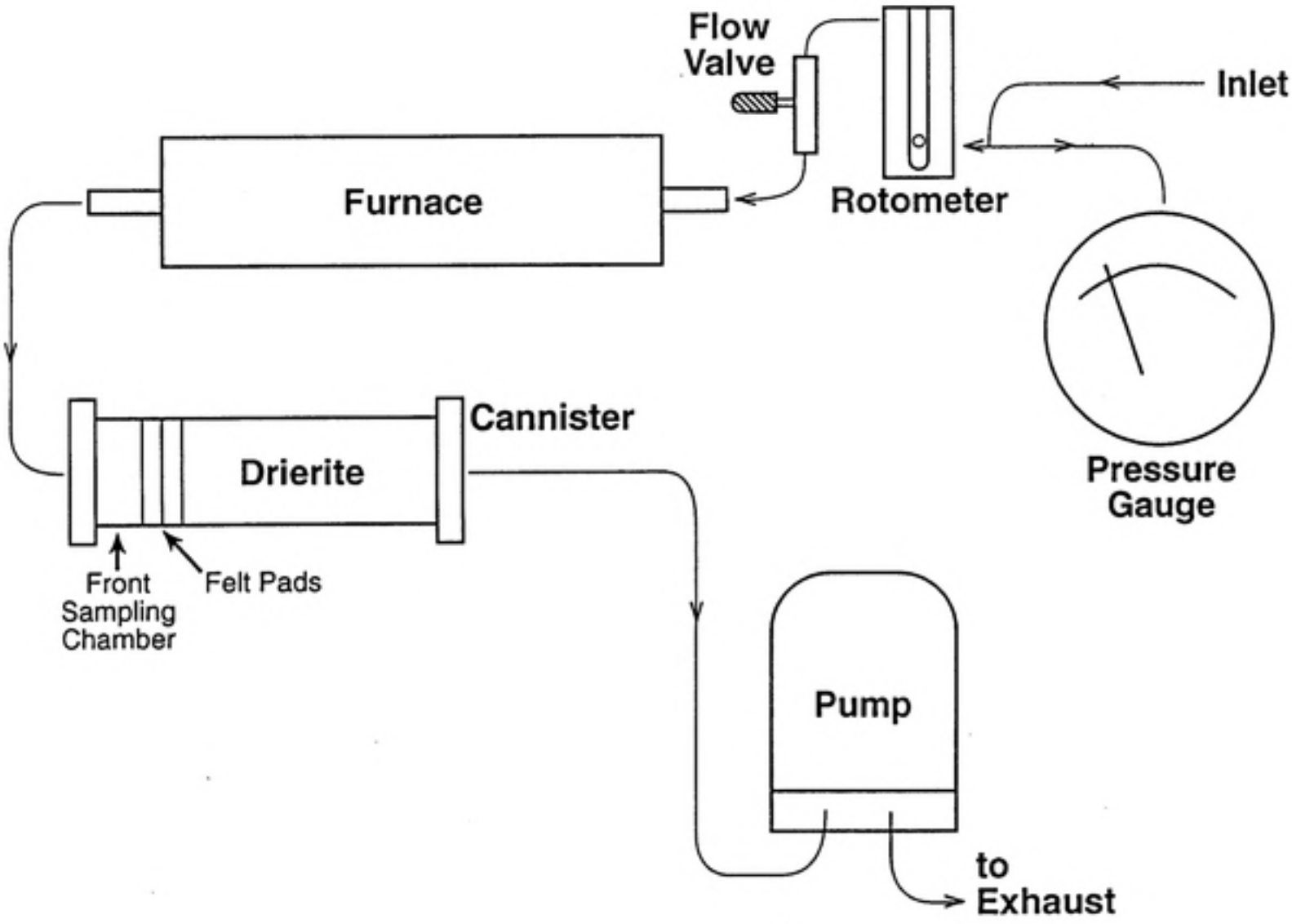

Figure 3 - ACT-100 Tritium/Carbon-14 Gaseous Effluent Sampler

(palladium/platinum) operating at approximately 550 degrees C. The furnace burns non-oxidized tritiated compounds and converts them to HTO. Gases then flow through the desiccant canister (Drierite - 8 mesh) which absorbs the newly oxidized HTO along with any previously oxidized HTO. The sampling flow rate is controlled by a variable pump and measured by a rotometer. The sampling line operates under a negative pressure which is monitored by a magnihelical gauge. The flow rate of the sampler was compared to a soap bubble chamber. It was found that the rotometer read 90 cc/min when the bubble chamber measured 100 cc/min.

The Radeco ACT-100 sampler was originally designed to sample up to two weeks at a time, much longer than the periods in which the incinerators would be burning radioactive materials. Typically, a radioactive burn would last 1 to 2 days, loading waste 6 hours each day. In an effort to concentrate the captured tritium, the desiccant canister was divided by felt pads into a front sample section and a larger rear portion. The front section was typically loaded with approximately 55 gm of drierite while the back portion held approximately 800 gm of drierite. Included with the standard drierite (white), the

front sampling section contained indicating drierite (blue granules) mixed in at different positions. The indicating drierite was added to reveal where the drierite was saturated with water.

The sampler was placed in an "instrument house" fabricated by Hi-Q Environmental Products Company (Model Wh-36). This instrument house allows air flow via louvers. The unit is equipped with a thermostatically-controlled fan to prevent overheating inside the unit.

Situated east of the sampler site is the NIEHS weather station, which is composed of a wind anemometer (Young Model 05103), a solar-shielded temperature probe (Young Model 41002), and a tipping scale rain gauge (Young Model 52202). Data are recorded by a data logger (Young Model 26700) every fifteen minutes and various data manipulations, such as wind speed and temperature averagings, are performed. These data are downloaded to spreadsheets twice a month. The data from this weather station can be helpful for determining the direction of the incinerator plume in relation to the position of the sampling station.

C. Analytical Methods

The extraction procedure begins by removing all the drierite from the front section of the desiccant canister and placing it into a beaker to be thoroughly mixed by stirring. From this mixture, 10 - 3 gm aliquots are weighed and placed in separate 20 ml plastic scintillation vials along with 18 ml of deionized water. The 10 vials are then placed on a shaker platform (Thermolyne Model Maxi-Mix III) in a customized Plexiglas tray. The vials are held tightly in the platform and the shaker set at 1200 speed for 4 hours. The force of the shaking process reduces the 8 mesh drierite granules into a white slurry.

Vials are removed from the shaker platform, vortexed for 1 minute, and individually filtered in a high pressure filter system (Microfiltration Corp.). The filter train includes one borosilicate filter (37 mm diameter) and a nitrocelluolose filter (47 mm diameter, .45 um pore size). The system is then pressurized at 30 psi for 3 minutes using a nitrogen cylinder. The bulk of the drierite is separated out by the borosilicate filter with a fine coating being left on the nitrocellulose filter. Typically 12 ml to 14 ml of clear filtrate are collected from the samples.

One 4 ml aliquot is then removed and placed into a separate 20 ml scintillation vial in preparation for counting. Fourteen ml of Ultima Gold LLT (UGLLT) scintillation cocktail (Packard) are then added to the 4 ml sample. UGLLT cocktail was specially formulated to be used in low level counting. A 4 ml sample was used because it was discovered that higher sample volumes tended to layer out in this cocktail.

The vials were then counted by using a Packard Tri-Carb Model 2500TR/LL Liquid Scintillation Analyzer. This instrument is equipped with a "Low Level Mode" for analyzing environmental samples by lowering the background count with an after-pulse rejection circuit. Although some efficiency is lost with this circuitry, the background is lowered significantly causing the overall E^2/B value ((efficiency)^2/background) to be greater. This value reflects the sensitivity of the instrument to measure low activity levels.

Samples in the low level count mode have to be dark adapted to reduce luminescence, a phenomena which can cause artificially high readings. In this project all samples were placed in the dark for a minimum of 60 minutes. After dark adaptation, the vials were counted for 720 minutes.

To determine the effects of quench, a special quench curve was developed using the same extraction procedures used with drierite from actual air samples. To generate this quench curve, 100 ul of a tritium stock solution containing an average of 8294 dpm of activity was added to fifteen 20 ml scintillation vials. Then 12 ml of scintillation cocktail was added to each of the 15 vials and the vials were counted for 10 minutes each. The counts from the 15 vials were averaged and the 10 vials with counts closest to the average were selected for the quench curve run.

To determine how the filtrate from the air sample processing quenches the activity, 3 gm of unexposed drierite were added to each of a number of 20 ml vials along with 18 ml of deionized water. These vials were then placed on shaker for 4 hours at 1200 speed, identical to the drierite samples taken from the air sampling runs. The filtrate was added to the 10 vials containing a known amount of activity. Starting with 1.5 ml of filtrate, increasing amounts of filtrate were added to the vials along with decreasing amounts of additional cocktail. This process ensured that all vials counted contained 18 ml of cocktail or cocktail-filtrate solution. Table 2 presents the amounts of filtrate and additional cocktail added.

Table 2 - Sample/Cocktail Mixtures for Extraction

Sample #	Initial amount of cocktail (ml)	Amount of Sample Added (ml)	Additional cocktail added (ml)	Total amount of cocktail (ml)
1	12	0.0	6.0	18
2	12	1.5	4.5	18
3	12	2.0	4.0	18
4	12	2.5	3.5	18
5	12	3.0	3.0	18
6	12	3.5	2.5	18
7	12	4.0	2.0	18
8	12	4.5	1.5	18
9	12	5.0	1.0	18
10	12	5.5	0.5	18
11	12	6.0	0.0	18

All the samples were consecutively run (at low level mode) for 30 minutes in the scintillation counter with a 60 minute pre-count delay to dark adapt the samples. The scintillation counter was programmed to count quench samples and to establish a quench curve, comparing the known spiked activity to the activity counted. This quench curve was then applied to later sampling runs so that cpm units could be converted to dpm units. The results are presented in Table 3 and the curve is depicted in Figure 4. The curve illustrates that the tSIE (indicator of quench) for the actual air samplers correlates with efficiencies between 36-37%. Unquenched samples with tritium counted in this same scintillation counter usually run at about 59-60% efficiency. As mentioned previously, the lower efficiency seen with these samples is

characteristic of both the scintillation counter's low-level counting mode and the low-level counting scintillation cocktail.

Table 3 - Counts for Quench Curve Standards

Sample #	Time	cpm	SIS	tSIE	Eff. %
1	30	3034	13.030	728.30	36.58
2	30	3215	11.560	552.27	38.77
3	30	3203	11.196	523.72	38.63
4	30	3147	10.988	501.01	37.95
5	30	3097	10.763	486.39	37.35
6	30	3027	10.512	461.45	36.51
7	30	2962	10.247	449.25	35.72
8	30	2892	10.046	431.38	34.87
9	30	2798	9.770	409.52	33.74
10	30	2692	9.565	396.19	32.46
11	30	2607	9.323	374.96	31.44

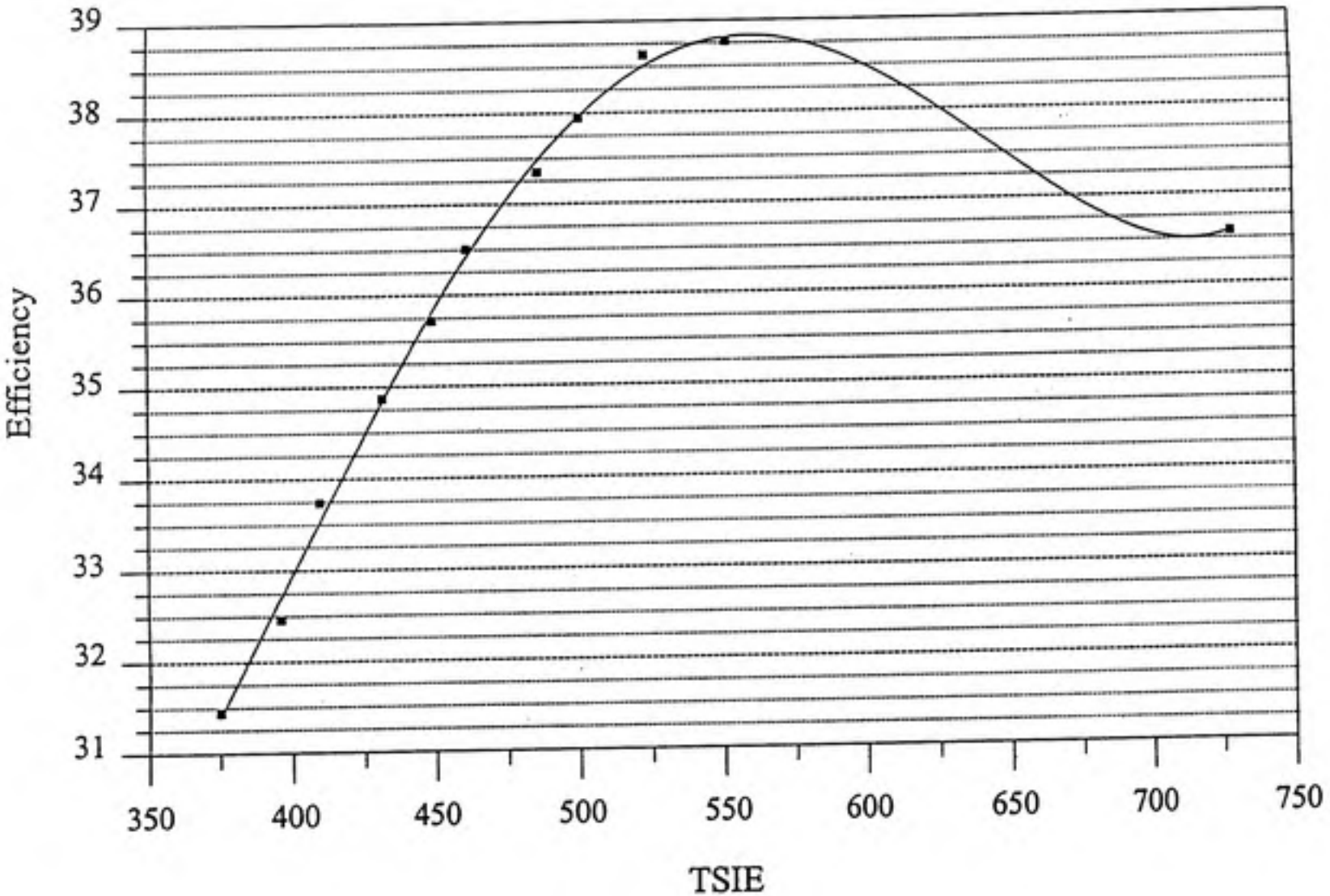

Figure 4 - Quench Curve

The extraction procedure was evaluated by spiking ten 3 gm samples of unexposed drierite with approximately 1671 dpm of tritiated water. This was accomplished by adding 20 ul of stock solution with a micropipetter. An attempt was made to add this stock solution slowly and evenly to all the drierite granules. As with all samples, 18 ml. of deionized water was added to the drierite and the samples were placed on a shaker for 4 hours. After high-pressure filtration, each of three 4 ml aliquots were placed in a 20 ml scintillation vial and counted for 30 minutes each. The total dpm for all 3 vials was added and the sum placed in the "Total dpm" column in Table 4. Since the 12 ml of filtrate counted only reflected 66% of the 18 ml of water added, the total dpm was adjusted by multiplying it by 1/.666 (1.5) and this calculated dpm was placed in the "Adjusted dpm" column. These adjusted dpm values were then divided by the original spiked activity (1671.1 dpm). Table 4 indicates that the average extraction efficiency was approximately 95.1%.

Table 4 - Counts for Extraction Efficiency Calculations

Sample #	Count Time (min)	Total dpm	Adjusted dpm	Eff. %
1	30	1121.24	1681.86	100.6
2	30	1087.64	1631.46	97.6
3	30	1099.05	1648.75	99.7
4	30	1122.11	1683.17	100.7
5	30	1133.62	1700.43	101.8
6	30	1162.35	1743.53	104.3
7	30	1094.81	1642.22	98.3
8	30	1217.54	1826.31	109.3
9	30	744.61	1116.90	66.8
10	30	813.60	1220.40	73.0
avg	30	1059.66	1589.49	95.1

- Spike 1671.1 dpm

D. Detection Limits

When interpreting results from environmental sampling events, especially where low concentrations are involved, a numerical lower limit must be established which helps determine if a particular sample contains above background amounts of a chemical or isotope. The "Detection Limit" (L_D), is a statistic used to represent this lower limit. The L_D represents the lowest possible activity present in a sample that when collected and analyzed, will have a 95% certainty of being detected (NCRP58, 1978).

The following is the formula for the L_D:

$$L_D = 2.71 + 4.65\sqrt{Background}$$ Equation 1

This formula indicates that the L_D is based solely on the background count. The background count used for this project was derived from drierite samples unexposed to air but processed using the same protocol performed on actual air samples. Table 5 presents the results of counts for these unexposed samples.

Table 5 - Counting for Drierite Controls

Samp. #	Count Time (min)	cpm	SIS	tSIE	Eff. %
1	720	2.35	13.093	477.35	37.09
2	720	2.32	13.133	483.14	37.33
3	720	1.73	14.374	488.26	37.52
4	720	2.12	14.565	480.01	37.22
5	720	1.91	14.403	479.33	37.18
6	720	1.77	14.644	478.37	37.14
7	720	1.87	14.047	477.77	37.14
8	720	1.64	14.534	479.67	37.22
9	720	2.35	12.804	465.99	36.80
10	720	2.93	11.516	470.15	36.80
avg	720	2.1	13.720	478.00	37.14
std dev		0.40	1.04	1.05	0.022

- Minumum 60 minute pre-count delay

The following series of equations depict the calculations used for arriving at the L_D:

$$L_D = 2.71 + 4.65\sqrt{Background}$$

$$L_D = 2.71 + 4.65\sqrt{2.1\ cpm\ x\ 720\ \text{min}}$$

$$L_D = 2.71 + 4.65\sqrt{1512}$$

$$L_D = 2.71 + 4.65(38.88)$$

$$L_D = 2.71 + 180$$

$$L_D = 183.52\ counts$$

The following related count rate is calculated by dividing the L_D by the total number of minutes the samples were counted (720 min):

L_D Rate = 183.52 counts/720 min. = 0.25 cpm

This rate is utilized in the following formula to calculate a Lowest Detectable Concentration (LDC):

$$LDC = \frac{(L_D\ Rate)\ (D_T)\ (W_T)}{(D_A)\ (W_A)\ (E_C)\ (E_X)\ (V)} \qquad \text{Equation 2}$$

D_T = Total Desiccant (gm)

D_A = Aliquot of Desiccant in Vial for Extraction Procedure(gm)

W_T = Total Water in Vial for Extraction Procedure (ml)

W_A = Aliquot of Water from Extraction Procedure used for Counting (ml)

E_C = Counting Efficiency Average for Sampling Run (%)

E_X = Extraction Efficiency (%)

V = Total volume of air sampled (m^3)

Note: One 3 gm aliquot is processed through the extraction procedure, reflecting only 3 gm/total desiccant (gm) of the

activity collected during the sampling run. To compensate the activity is multiplied by the following:
(total desiccant (gm))/3 gm.

Note: 18 ml of deionized water is added to the 3 gm aliquot of drierite. The extraction procedure produces 13 ml - 15 ml of clear filtrate. Only a 4 ml aliquot of the filtrate is placed in a scintillation vial for counting. To compensate, the dpm value has to be multiplied by 18/4.

A typical LDC can be calculated using values that represents a typical run. The following values could be placed in the formula to derive an expected LDC:

D_T = 55 gm
D_A = 3 gm
W_T = 18 ml
W_A = 4 ml
E_C = 36.5%
E_X = 95.1%
V = .036 m^3

$$\text{Typical LDC} = \frac{(.25 \text{ cpm})\ (55 \text{ gm})\ (18 \text{ ml})}{(3 \text{ gm})(4 \text{ ml})(.365)(.951)(.036 \text{ m}^3)}$$

Typical LDC = 1569 dpm/m^3
Typical LDC = 714 pCi/m^3

E. Gaussian Dispersion Calculations

A screening model and air dispersion equations were utilized to estimate what the expected concentration of tritium-in-air could be at the air sampling station. Both the model and the equations are based on a Gaussian distribution. Gaussian or normal distributions (see Figure 5) of populations are the familiar bell-shaped curves with a central mean bordered by values which deviate to either side of the mean. A measurement of variability of these deviant values is indicated by the standard deviation (σ) of a sample or population.

Diffusion models and equations are based on a variety of algorithms, some of which have been developed for specific applications. Some models and equations, for instance, may require detailed wind data while others can be satisfied with more commonly recorded wind parameters. The following is a diffusion equation used for this project to estimate the concentration at the sampling station (Turner, 1969):

$$X(x, y, z; H) = \frac{Q}{2\pi\sigma_y\sigma_z u} \exp\left[-1/2\left(\frac{y}{\sigma_y}\right)^2\right]$$

$$\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]\right\} \qquad \text{Equation 3}$$

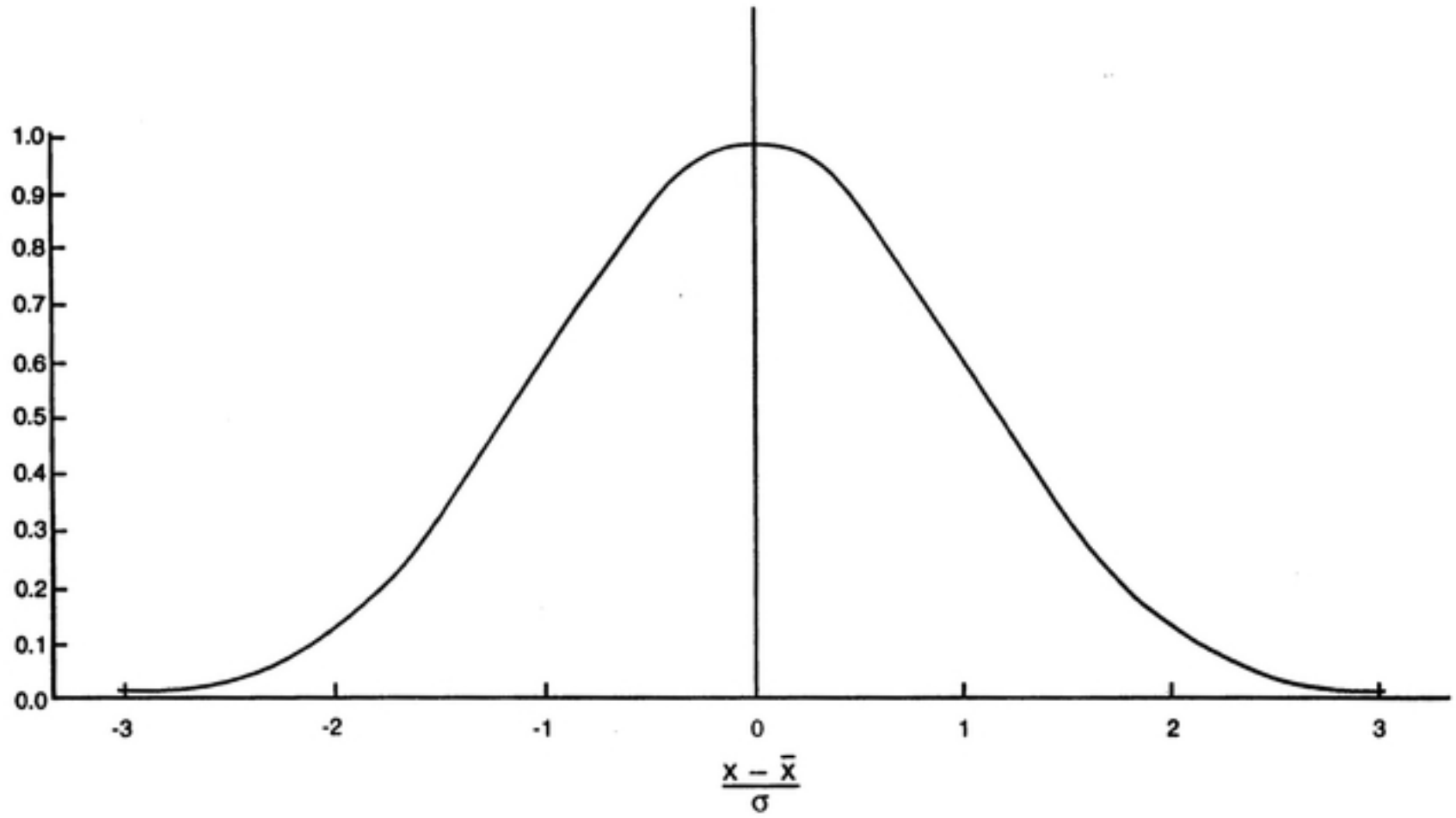

Figure 5 - Gaussian or Normal Distribution

In Equation 3, X represents the concentration of a contaminant at a particular point (x,y,z) in space which is x meters downwind from the source. The y and z represent the distance from the plume centerline in the horizontal and vertical planes respectively (see Figure 6). H is the effective stack or emission height representing the sum of the physical stack height and the plume rise. The plume rise represents the distance above the stack that the emission gases are carried (upward) by buoyancy and momentum forces before essentially leveling off. The emission rate (Q) represents a steady-state release of the contaminant. The standard deviations (σ_y , σ_z) reflect the rate of decrease of contaminant concentrations at increasing distances from the plume centerline in the horizontal/vertical planes respectively. The mean wind speed (u) is also incorporated in the equation.

As the formula indicates, the concentration downwind at point (x,y,z) is directly related to the emission rate and indirectly related to the wind speed, horizontal standard deviation, and the vertical standard deviation. As the wind speed increases it tends to dilute the plume. The

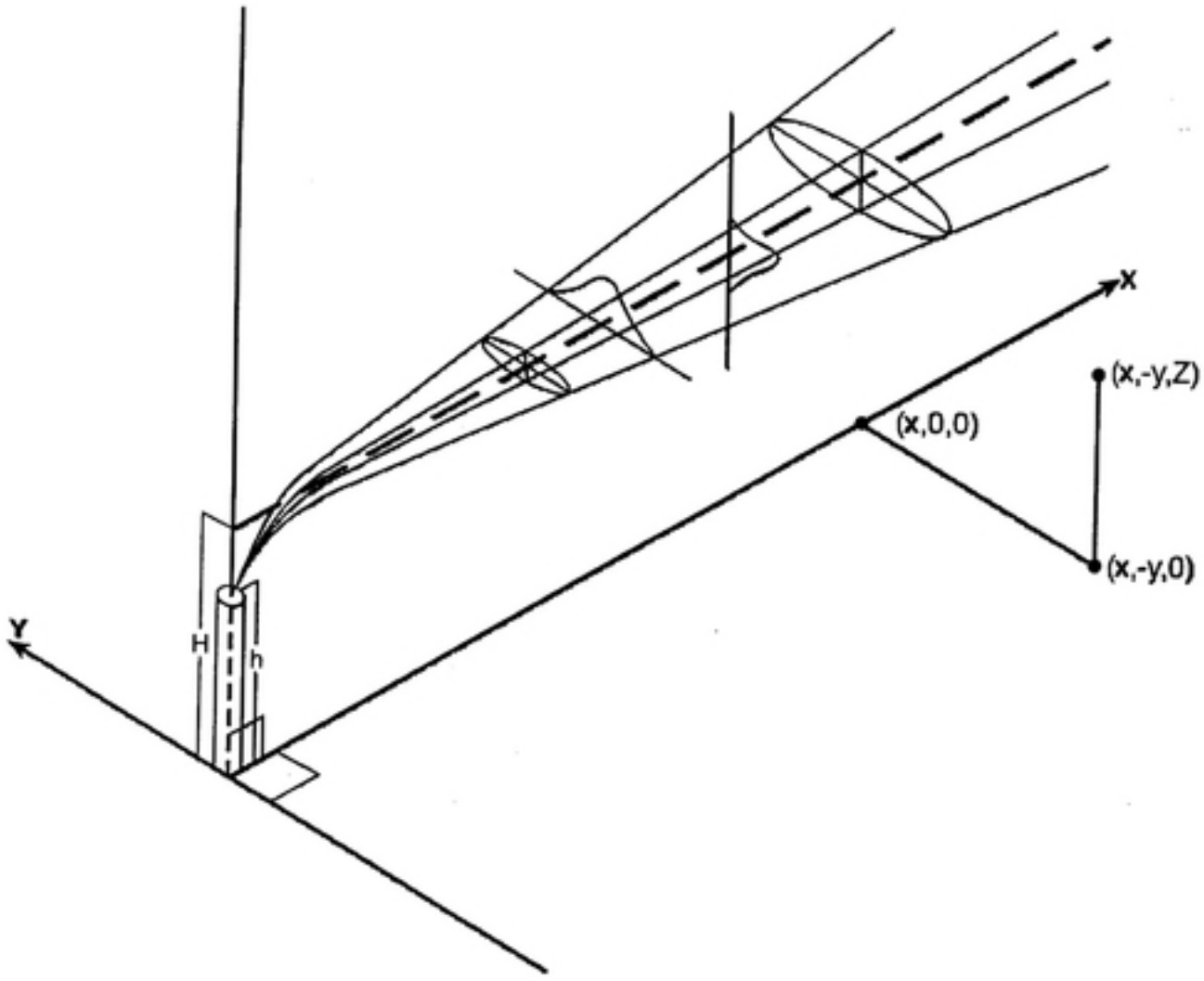

Figure 6 - Gaussian Plume Dispersion

standard deviation is indirectly related to the atmospheric stability. As the stability of the atmosphere decreases due to changes in temperatures, the mixing action of turbulent air masses increases which would be reflected by higher standard deviations.

When utilizing Equation 3 certain assumptions must be made. First, as an upper limit, it is assumed that the wind is blowing the incinerator plume directly and continuously towards the air sampling station. In calculating the estimated concentration at the sampling site, a wind speed of 2.43 m/sec. (~5.45 mph) was used in Equation 3. This value was derived from averaging hourly wind speed measurements taken during sampling events. Screen3, a screening model developed for evaluating chemical releases, was used to estimate the σ_y, σ_z, and plume rise (EPA, 1995b). The input and output for the Screen3 model is included in Appendix D. A neutral atmospheric stability class (D or 4) was selected to give a general indication of plume dispersion. The stack height (11.78 m), the stack diameter (.58m), and a stack gas velocity (9.0 m/sec) were required inputs. Also, stack gas temperature (945° K), ambient temperature (293° K), building and receptor heights (10.49 m, 10.13 m), and minimum/maximum building dimensions

(75 m, 115 m) were also entered into the model. This information was used by the model to provide estimates of plume height (H), σ_y, σ_z, and concentrations at various receptors.

In this particular case the Screen3 model estimated a plume height of 16.57 m, 6.44 m above the sampler's height of 10.13 m. The model also estimated the σ_y and σ_z to be 4.31 m and 6.48 m respectively (at 50 m). This output data suggest that the sampler would experience tritium concentrations 1 standard deviation (σ) less than centerline values. One standard deviation represents approximately 61% of the plume centerline concentration. Figure 7 depicts the plume characteristics using the Screen3 model's estimates.

A release rate of 1 gm/sec was used in the Screen3 model as a reference number. With this release rate the model calculated the concentration at 50 m to be 1398 ug/m^3. Knowing this allows the modeller to input different release rates assuming all other parameters remain constant. For example, if the

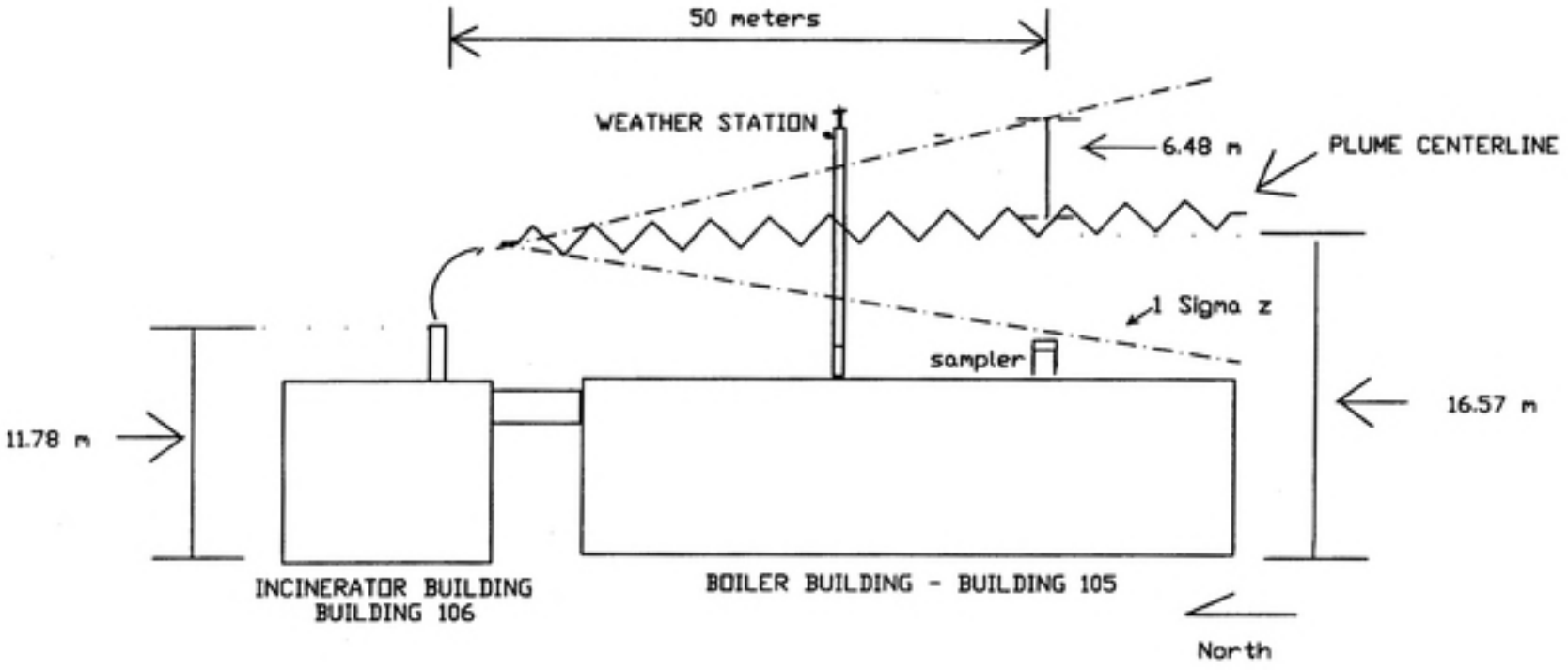

Figure 7 - Incinerator Plume - Sigma z

emission rate was decreased to 0.1 gm/sec, then the modeller could simply multiply the output concentration (1398 ug/m^3) by 0.1 to arrive at 139.8 ug/m^3.

As previously mentioned, the NIEHS limits the activity loaded into the incinerator to a maximum of 47 mCi (per 24 hour period) but the actual activity incinerated is usually much less. For inputting data into the model and equation, it was assumed that all 47 mCi was burned. Since most of a daily burn actually occurs within a 6 hour period, the average release rate during this burn time would be approximately 2 uCi/sec (dividing 47 mCi by 21,600 sec). Multiplying this emission rate (2 uCi/sec) by the concentration factor from the model (1.398E -03) gives an estimated airborne tritium concentration of 2796 pCi/m^3, close to 4 times above the "Typical LDC" (714 pCi/m^3). The indication by this screen model is that if the wind (2.43 m/sec) is blowing directly towards the sampler with an continuous emission rate of 2 uCi/sec, the sampling system could theoretically detect it.

In addition to using the Screen3 model, Equation 3 was also used to estimate the concentration at the sampler. By inputting known/estimated parameters

and assuming the wind is blowing directly towards the sampler, Equation 3 appears as follows:

$$X(\mathbf{x},\mathbf{y},\mathbf{z};\mathbf{H}) = \frac{2\,uCi/\sec}{2\pi(4.31)(6.48)(2.43)} \exp\left[-1/2\left(\frac{0}{4.31}\right)^2\right]$$

$$\left\{\exp\left[-\frac{1}{2}\left(\frac{6.44}{6.48}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{10.41+16.57}{6.48}\right)^2\right]\right\}$$

$$(\mathbf{x},\mathbf{y},\mathbf{z};\mathbf{H}) = \left(\frac{2}{429}\right)(1)(.61)$$

$$(\mathbf{x},\mathbf{y},\mathbf{z};\mathbf{H}) = 2.84\ nCi/m^3$$

$$(\mathbf{x},\mathbf{y},\mathbf{z};\mathbf{H}) = 2840\ pCi/m^3$$

The equation's output value of 2840 pCi/m^3 is relatively close to the model's estimated concentration of 2796 pCi/m^3. This would suggest that the Screen3 model processes values in a way similar to Equation 3. Both indicate that if the wind was directly blowing towards the sampler, and a continuous emission rate of 2 uCi/sec was maintained, this sampling system (with a LDC of 714 pCi/m^3) could detect the tritium.

F. Industrial Source Complex Short Term II Dispersion Model

The Screen3 model is a relatively simple air dispersion model which by way of a number of assumptions can give conservative concentration

values at various receptor points (EPA, 1995b). There are other models such as the Industrial Source Complex Short Term Dispersion Model II (ISCST2) which are more refined, requiring more actual data but performing more realistic calculations (EPA, 1992b). For this project, the ISCST2 model was used to help select the sampling location and to provide more realistic airborne tritium concentrations.

In addition to the data which was entered into the Screen3 model, the following supplemental information was required by the ISCST2 model:

1) hourly temperature, wind speed, wind direction, and stability data from Raleigh-Durham Airport;
2) information based on computations estimating air flow patterns around the incinerator and boiler building;
3) surrounding elevations at 50 m coordinates.

The results from the ISCST2 air modeling exercise indicated that a location 50 m due south of the incinerator stack would most likely experience the highest concentrations of tritium from stack emissions. This would place the sampler on the rooftop of the adjacent boiler building, Building 105. Using Raleigh-Durham weather data for all of 1991, the highest 1-hour average calculated from

the model was 1520 pCi/m^3. This can be compared .to the 2796 pCi/m^3 calculated from Screen3 model. Table 6 and Appendix D present the output from the ISCST2 model indicating the highest concentrations calculated for the ISCST3 model (at 50 m due south) for different averaging periods. As mentioned, the release rate of 2 uCi/sec (used in the ISCST2 model) was based on the assumption that 47 mCi (NIEHS - 24 hr limit) was released in only a 6-hr period. This assumption is valid when estimating 1-hr averages but since the model assumes that the same release rate occurs every hour of a year, the estimates for 24-hr and annual averages would be unrealistically high.

Table 6 - ISCST2 Concentrations

Time Period	Concentration (pCi/m^3)
Highest 1-hr avg	1520
Highest 24-hr avg	419
Annual avg	22

G. Meteorological Conditions

The NIEHS has a small meteorological station located on top of the same building (Building 105) used for air sampling. Weather data from this

station are logged every 15 minutes and the data are processed into averages and standard deviations. Temperature, wind speed, wind direction, and precipitation are recorded simultaneously. Data from this datalogger were downloaded and entered into WRPLOT, a windrose plotting program (EPA, 1998). The results of this program were printed out and are included in Appendix C.

As the Gaussian Plume Equation indicates, the further the sampler or receptor is located from the plume centerline, the lower the expected concentration would be at that point. The sampler in this project was placed directly south of the incinerator stack and would experience the highest emission concentrations when the wind was blowing from due north (0°). As the wind deviates from 0°, the concentration would eventually decrease to a value below the LDC. As mentioned in Section IX.E., the estimated concentration at the sampler with the wind blowing from 0° is approximately 2800 pCi/m^3, a level detectable according to LDC calculations. It would be helpful to know how far off from 0° the wind could vary and still have estimated air concentrations above the LDC of 714 pCi/m^3 at the sampler. To determine this, the σ_y

(4.31 m) from the Screen3 model was used to approximate the number of degrees represented by a one standard deviation. By establishing a triangle with an opposite side of 4.31 m (σ_y) and an adjacent side of 50 m (distance from sampler), the included angle can be trigonometrically derived. Equation 4 indicates that 1 standard deviation is approximately 4.93 degrees (in the horizontal plane). Figure 8 illustrates the distances and angle related to Equation 4.

Opposite side/adjacent side = Tangent of angle

4.31 m/50 m = .0862 Equation 4

Tan 4.93° = .0862

The next step in determining the limits of wind variation is to calculate the ratio of the LDC and the maximum estimated concentration (wind blowing from due north). Dividing 714 by 2800 gives a quotient of 0.25. This indicates that the horizontal limit away from due north would be reflected when the horizontal component of the Gaussian Plume Equation, $\exp\left[-1/2\left(\frac{y}{\sigma}\right)^2\right]$, is equal to .25 (lowering concentration to 25% of centerline).

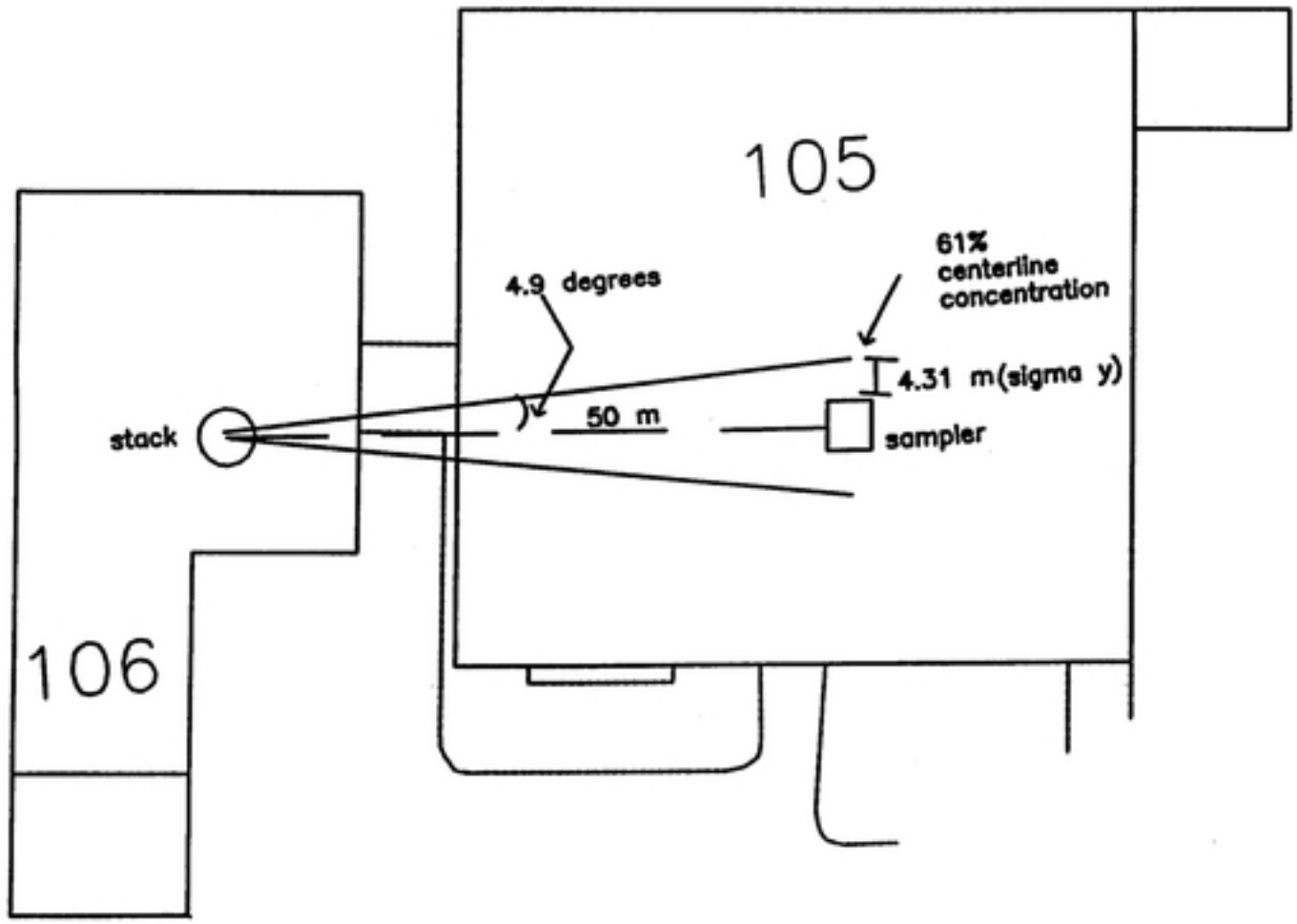

Figure 8 - Incinerator Plume - Sigma y

When Equation 5 (see below) is solved for y, it indicates that with a σ_y of 4.93°, the wind blowing at 8° from due north would decrease the concentration at the sampler to 25% of the plume centerline concentration Again, this value (0.25) is the ratio of LDC and modeled concentration.

$$\ln .25 = \left[-1/2 \left(\frac{y}{4.93} \right)^2 \right] \qquad \text{Equation 5}$$

y = 8

Based on this calculation, a wind that is blowing between the bearings of 352° and 8° would allow for detectable concentrations, assuming that the wind speed is blowing at 2.53 m/sec and the release rate is equal to or greater than 2 uCi/sec. According to wind rose data from the Raleigh-Durham Airport (see Appendix F), regional winds blow from due north less than 10% of the time indicating that the concentration at the sampler would usually fall below the LDC (if other parameters remain constant).

H. Analytical Results

1. Summary of Counts

Table 7 summarizes the counting results from both the control runs and the air sampling runs, Series A - F. The cpm, "above-control cpm", and dpm

values of the sampling series reflect the average of the 10 vials counted from the sampled drierite (see Appendix A). The "above-control cpm" was calculated by simply subtracting the control series cpm (2.1 cpm) from the sampling series cpm's. Series A's "above-control cpm" was also corrected for decay because of the 952 day delay between the sampling event and the counting date. The other sampling series were counted closer to their respective sampling event and did not need half-life correction. The cpm values for all the series except Series C were greater than the control. Only Series A's average "above-control cpm" was greater than the L_D value of 0.25 cpm.

The dpm values were derived by dividing the "above-control cpm" by the respective counting efficiency. Standard deviations for the cpm values (before subtraction of control) are included to give perspective on the variability of the data. These standard deviations range from 0.204 (A) to 0.460 (B).

Table 7 - Air Sampling Summary of Counts

Series	Sampling Dates	cpm	Above Contr. cpm	dpm	SIS	tSIE	Eff. %
Contrl avg	*None*	*2.1*			*13.72*	*478*	*37.14*
Contrl std dev	None	.396			1.045	6.207	.0218
A avg	*11/21/94-12/22/94*	*2.36*	***.30****	*.84*	*12.066*	*453.36*	*35.99*
A std dev		.204			.420	5.069	.264
B avg	*3/6/96-3/7/96*	*2.27*	*.17*	*.46*	*13.698*	*471.44*	*36.85*
B std dev		.460			.562	12.78	.535
C avg	*3/12/96-3/14/96*	*2.01*	*below contr.*	*---*	*13.003*	*472.42*	*36.88*
C std avg		.333			.832	3.88	.171
D avg	*5/14/97*	*2.33*	*.23*	*.63*	*12.774*	*460.845*	*36.38*
D std dev		.26			.617	3.64	.176
E avg	*7/16/97*	*2.24*	*.14*	*.39*	*13.0533*	*460.214*	*36.34*
E std dev		.26			.617	3.64	.176
F avg	*12/18/97-12/19/97*	*2.24*	*.14*	*.38*	*13.225*	*474.25*	*36.97*
F std dev		.375			.908	3.23	.134

* reflects half-life correction

2. Summary of Concentrations

All the "above-control cpm" values were used to calculate tritium-in-air concentrations by placing them in Equation 6.

$$\text{Estimated Air Concentration} = \frac{(R)\ (D_T)\ (W_T)}{(D_A)\ (W_A)\ (E_C)\ (E_X)\ (V)} \qquad \text{Equation 6}$$

R = Sampling Count Rate (above-control cpm)

D_T = Total Desiccant (gm)

D_A = Aliquot of Desiccant in Vial for Extraction Procedure (3 gm)

W_T = Total Water in Vial for Extraction Procedure (18 ml)

W_A = Aliquot of Water from Extraction Procedure (4 ml)

E_C = Counting Efficiency Average for Sampling Run (%)

E_X = Extraction Efficiency (.951)

V = Total Volume of Air Sampled (m^3)

The concentrations ranged from 115 pCi/m^3 (Series A) to 550 pCi/m^3 (Series D). Since Series C had a cpm lower than the control, its concentration was not calculated. Specific LDC's were calculated for each sampling series using Equation 2 (See Section IX.D.) and presented in Table 8. Sampling Series A was the only sampling series with an estimated concentration greater than its respective LCD. This is consistent with the fact that Series A was the only series with an average "above-control cpm" greater than the L_D value of 0.25 cpm. Series A was also the only sampling performed on the NIEHS

North Campus (distant from the incinerators). The purpose for this series was to determine any background tritium concentrations in ambient air.

When the samplers were being operated, the air flow was noted and logged. The air flow in the Radeco ACT-100 was subject to drifting, usually in the downward direction. Before the sampler was used in the field, it was determined by a soap bubble test that the rotometer was registering 90 cc/min when the sampler was actual operating at 100 cc/min (target rate). There was no apparent way to adjust the rotometer to read more accurately. For the purposes of this project, the logged sampling rates were adjusted by taking the field values and multiplying them by 1.11 (100/90). Since the air flow rate typically drifted downward during the course of the sampling event, an average air flow was estimated by averaging the flow rates between readings. The estimated total volumes sampled are also indicated in Table 8.

Table 8 - Concentration Estimates of Sampling Series

Series	Sampling Time (hr)	Approx. Sampling Rate cc/min	Total Volume Sampled m^3	Grams in Sampling Chamber	dpm 3 gm Drier.	Total dpm in Drierite	Approximate Tritium Activity Released (mCi)	Estimated Air Concentration pCi/m^3	LDC pCi/m^3
A AVG	681.1	105.5	4.31	825	3.97	935	ambient air	**115**	96
B AVG	11.54	111	.076	47	2.17	34	1.008	204	301
C AVG	7.28	111	.048	52	----	----	96.61	----	528
D AVG	7.18	101	.043	48	2.98	52	12.05	550	550
E AVG	5.25	111	.035	41	1.85	25	4.3	325	578
F AVG	13.40	94.4	.076	62	1.80	37	18.81	221	396
Avg	8.9	106	.056	50	2.77	---			

3. Student's t-Test

To determine if the sampling results were statistically significant when compared to the control samples (unexposed to air), the Student's t-Test was performed on the cpm values (before control counts were subtracted). This statistical test is used to determine if two sampling groups represent two different populations or simply variation within the same population. The t-Test version used for this project assumed a two-tailed distribution and equal variances. The cpm values from the sampling series (ten vials) and the control series (ten vials - unexposed drierite) were inputted on an Excel spreadsheet. Table 9 indicates the t-Test values when each sampling series was compared with the control series. These values in the table represent the probability that there is no real difference in activity between air sampling series and the unexposed control series. According to the t-Test none of the sampling series were below the selected 0.05 threshold. This suggests that the activity indicated by the cpm values for the sampling series probably did not represent absorbed tritium but were reflecting background from the counting process.

Table 9 - t-Test Calculations

Series A	Series B	Series C	Series D	Series E	Series F
.084	.413	.525	.251	.364	.434

4. Estimating wind direction effects on Series F sampling

During sampling runs, the wind will vary in direction and speed. To estimate the effects of varying wind directions, Series F was used as a model because it was during this particular sampling run that the winds were most directly blowing from the north. Since the Screen3 model indicated that the sampler was located approximately 1 standard deviation vertically below the centerline of the plume (see Section IX.E.), the sampler would by Gaussian Plume theory experience approximately 61% of the centerline plume concentration (at 50 m) even when the wind is blowing directly towards the sampler. Naturally, as the wind direction varies from 0 degrees (sampler is due south of incinerator stack), the sampler would experience decreasing concentrations of tritium vapor. Using the standard deviation in degrees (4.93) (see Equation 4), fractional estimates can be made of the centerline concentration when the wind is blowing from various directions. First the number of degrees away from zero (north) is divided by 4.93. This gives the

number of standard deviations away from true north. Using the Gaussian Plume Equation, the y coefficient can be calculated to determine during each burn period what portion of that burn passed by the sampler. This figure is then multiplied by the tritium activity (mCi) burned during that period (see Appendix E) which generates an "effective activity" (see Table 10). All the separate burn periods can be totaled to produce a "Total Effective Activity" representing the released amount that theoretically would be collected by the sampler during the whole sampling period. Dividing the total effective activity (0.38 mCi) by the amount of time that the sampler was running (13.4 hours), would give a release rate (Q) of 0.0078 uCi/sec. The following calculations input this rate of release into Equation 3.

$$X(\mathbf{x},\mathbf{y},\mathbf{z};\mathbf{H}) = \frac{0.0078}{2\pi(4.31)(6.48)(2.43)}$$

$$\left\{ \exp\left[-\frac{1}{2}\left(\frac{6.44}{6.48}\right)^2 \right] + \exp\left[-\frac{1}{2}\left(\frac{10.13+16.57}{6.48}\right)^2 \right] \right\}$$

$$X(\mathbf{x},\mathbf{y},\mathbf{z};\mathbf{H}) = \frac{0.0078}{2\pi(4.31)(6.48)(2.43)} \quad (.61)$$

$$X(\mathbf{x},\mathbf{y},\mathbf{z};\mathbf{H}) = 1.1\,E-5\,uCi/m^3$$

$$X(\mathbf{x},\mathbf{y},\mathbf{z};\mathbf{H}) = 11\,pCi/m^3$$

Since 11 pCi/m^3 is nearly 2 orders of magnitude less than the LDC for Series F (396 pCi/m^3), it is

unlikely that sampler could effectively measure this sampling run.

Table 10 - Wind Direction Corrections - Series F

Date of Burn	Time of Burn	Activity of Burn (mCi)	Wind Dire.	# of S.D.*	Y Coefficient	Effective Activity (mCi)
2/18/97	9:55 am	9.9784E-04	28	5.7	8.8E-08	8.8E-11
2/18/97	10:07 am	9.9784E-04	38	7.7	1.3E-13	1.3E-16
2/18/97	10:35 am	9.9784E-04	38	7.7	1.3E-13	1.3E-16
2/18/97	10:48 am	9.9784E-04	0	0.0	1.0	1.0E-03
2/18/97	11:15 am	8.9861E-02	14	2.8	0.020	1.8E-3
2/18/97	11:56 am	2.2269E-03	36	7.3	2.7E-12	6.0E-15
2/18/97	12:35 pm	4.4638E-03	26	5.1	2.6E-06	1.2E-08
2/18/97	13:14 pm	4.4538E-03	16	3.2	0.0060	2.7E-5
2/18/97	14:22 pm	1.0805E-01	10	2.0	0.135	0.015
2/18/97	14:35 pm	1.0678E+01	347	2.6	0.034	0.36
2/18/97	15:30 pm	9.9569E-04	314	9.3	1.6E-19	1.6E-22
Total		10.892				0.38

*Standard Deviations

X. DOSE CALCULATIONS

Internal dose from tritium emissions could be caused by inhalation and skin absorption. In an attempt to determine potential health implications (from tritium inhalation) to a person standing on the rooftop of the building adjacent to the incinerator stacks, assumptions have to be made concerning respiratory rate and lung volume. An estimate of these parameters can be derived by

using a "Reference Man" who represents a typical person, anatomically and physiologically. In the "Report of the Task Group on Reference Man" (ICRP, 1975), a male adult during light activity would exchange a volume of 9600 liters of air during an 8-hour work day. Using the conservative concentration (2.8E 03 pCi/m^3) from the Gaussian Dispersion calculations and assuming 100% absorption, the total daily tritium intake of 5808 Bq/8 hour day (by inhalation) can be derived by the following equations:

1) (2.8E 03 pCi/m^3) X (2.2 dpm/pCi) (1 Bq/60 dpm)) = 605 Bq/m^3.
2) 9600 liters X 1 m^3/1000 liters = 9.6 m^3
3) 605 Bq/m^3 X 9.6 m^3 = 5808 Bq/8 hour day.

EPA has published a guidance document listing dose conversion factors according to type of isotope and mode of intake (EPA, 1988). These factors can be used to convert the intake of an isotope (ex. - inhaled tritiated water vapor) to a committed dose equivalent. The particular factor for inhaled tritiated water vapor is 1.73E -11 Sv/Bq. Multiplying this factor times the total daily tritium intake (5808 Bq/8 hour day) gives a total committed dose of 1.00E -07 Sv/ 8 hour day. If a man worked near the site of the air sampler for a whole year (250 days), the total effective dose is

2.50E-5 Sv/250 days (assuming the incinerator is used every working day and the wind is blowing directly towards the individual). Since 1 sievert equals 100 rem, this person potentially could be receiving 2.50E -03 rem/yr from this exposure. The recommended dose limit from the NRC for occupational exposure is 5 rem and for the general public is .1 rem. This 250 day exposure represents 0.05% and 2.5% of those limits respectively.

XI. CONCLUSIONS

The results from this study indicate that the ACT-100 Tritium Sampler potentially could detect airborne tritium only if the maximum release rate of 2 uCi is maintained and the wind is blowing within ± 8° of a straight-line direction towards the sampler. In actuality, these conditions are not usually met. If these conditions are met, the highest potential tritium concentration (estimated by modeling) from plume emissions is approximately 2800 pCi/m^3.

Dose calculations indicate that a person working near the sampler location receives approximately 1E- 05 rem/8 hr or 2.5 E- 03 rem/250 work days. This translates into 0.05% of the occupational dose limit. Since the wind conditions vary

significantly and the maximum release rate is usually not released, actual dosages would probably be much less than these figures.

The estimated air concentrations derived from the drierite exposed to ambient air samples (during incinerator burns) ranged from 115 pCi/m^3 to 550 pCi/m^3. All these estimates were less than the their respective LDC's except Series A. Series A's estimated air concentration was 115 pCi/m^3 with a respective LDC of 96 pCi/m^3 giving a ratio of approximately 1.2 above the LDC.

It is doubtful that these air concentrations derived from exposed drierite represent any sampled activity. This conclusion is based on the fact that only Series A had activity levels above the L_D and an estimated concentration level above the LCD. Also, the results from the Student's t-Test indicated that there was no significant difference between the control series cpm and the sampling series cpm's (including Series A). It can be concluded that if the cpm values are not significantly above the control (background), then the air concentrations derived from those cpm values would not reflect above-background concentrations.

Series F was the only sampling series which experienced winds blowing from the north for any significant period of time. The estimated average air concentration during the sampling period (using Gaussian Plume equations) was 11 pCi/m^3, well below the LDC for Series F (398 pCi/m^3). This concentration (11 pCi/m^3) is also well below the estimated concentration of 221 pCi/m^3 derived from the sampling/analysis of drierite exposed to ambient air samples during the Series F sampling run.

Although it was determined that the sampling/analysis system used for this project was unable to actually detect airborne tritium vapor, an extraction procedure was developed which may have potential in other applications where higher levels of airborne tritium exists.

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Appendix A - Series A-F Scintillation Counting Tables

Table 11 - Appendix A - Series A Counts

#	Count Time (min)	cpm	Corrected cpm for Half-life	SIS	tSIE	Eff. %
1	840	2.55	2.62	11.912	447.76	35.68
2	720	2.47	2.53	11.572	448.17	35.73
3	720	2.62	2.70	12.010	444.88	35.57
4	720	2.42	2.47	11.453	454.76	36.09
5	720	2.37	2.41	11.771	453.71	36.04
6	720	2.15	2.16	12.779	454.17	36.04
7	720	2.22	2.24	12.059	453.22	35.99
8	720	1.99	1.99	12.583	459.03	36.29
9	720	2.10	2.10	12.300	457.82	36.24
10	720	2.37	2.41	12.223	460.09	36.34
avg	720	2.32	2.36	12.066	453.36	35.99
std dev		0.204	0.232	0.420	5.069	0.264

- Minimum 60 minute pre-count delay
- Using 3 gm samples from a 825.4 gm total
- Sample ran 681.10 hours from 11/21/94 - 12/22/94

Table 12 - Appendix A - Series B Counts

#	Count Time (min)	cpm	Corrected cpm for Half-life	SIS	tSIE	Eff. %
1	720	2.59	2.60	13.953	500.67	37.93
2	720	1.93	1.93	12.844	449.99	35.78
3	720	3.41	3.44	13.280	465.40	36.57
4	720	2.16	2.16	13.769	468.98	36.75
5	720	2.12	2.12	13.773	468.41	36.71
6	720	2.40	2.41	12.921	466.94	36.66
7	720	1.97	1.97	14.354	475.17	37.01
8	720	1.89	1.89	13.781	473.09	36.93
9	720	1.97	1.97	14.605	474.32	36.97
10	720	2.13	2.13	13.663	478.45	37.14
avg	720	2.27	2.27	13.698	471.44	36.85
std dev	720	0.460	0.470	0.562	12.78	0.535

- Minimum 60 minute pre-count delay
- Using 3 grams samples from a 46.6 gm total
- Sample ran 11.54 hours from 3/6/97-3/7/97

Table 13 - Appendix A - Series C Counts

#	Count Time (min)	cpm	Corrected cpm for Half-life	SIS	tSIE	Eff. %
1	720	1.83	1.83	14.350	473.68	36.97
2	720	1.81	1.81	14.443	472.99	36.93
3	720	2.30	2.31	12.703	465.82	36.62
4	720	2.08	2.08	12.680	473.90	36.97
5	720	2.12	2.12	12.809	474.81	37.01
6	720	2.08	2.08	11.869	472.23	36.88
7	720	1.99	1.99	12.690	472.58	36.93
8	720	1.88	1.88	12.656	471.60	36.88
9	720	1.85	1.85	12.370	466.98	36.66
10	720	2.16	2.16	13.463	479.65	37.22
avg	720	2.01	2.01	13.003	472.42	36.88
std dev		0.333	0.333	0.832	3.88	0.171

- Minimum 60 minute pre-count delay
- Using 3 grams samples from a 51.76 grams
- Sample ran 7.28 hours from 3/12/96 - 3/14/96

Table 14 - Appendix A - Series D Counts

#	Count Time (min)	cpm	Corrected cpm for Half-life	SIS	tSIE	Eff. %
1	720	2.06	2.06	13.426	462.50	36.48
2	720	2.10	2.10	13.328	461.54	36.43
3	720	2.03	2.03	12.978	460.47	36.34
4	720	1.84	1.84	12.214	458.46	36.24
5	720	2.30	2.30	12.760	467.70	36.71
6	720	3.39	3.40	12.762	465.08	36.57
7	720	2.84	2.85	11.61	463.56	36.52
8	720	2.27	2.27	13.131	463.20	36.48
9	720	2.36	2.36	11.991	445.23	35.57
10	720	2.07	2.07	13.535	460.71	36.38
avg	720	2.33	2.33	12.774	460.845	36.38
std dev		0.461	0.464	0.647	6.06	0.310

- Minimum 60 minute pre-count delay
- Using 3 grams samples from a 47.8 gm total
- Sample ran 7.18 hours on 5/14/97

Table 15 - Appendix A - Series E Counts

#	Count Time (min)	cpm	Corrected cpm for Half-life	SIS	tSIE	Eff. %
1	720	2.25	2.25	12.146	453.90	36.04
2	720	2.33	2.33	14.043	460.35	36.34
3	720	2.67	2.67	12.427	462.72	36.48
4	720	2.04	2.04	13.612	461.96	36.43
5	720	1.87	1.87	12.251	457.85	36.24
6	720	1.95	1.95	13.122	461.39	36.38
7	720	2.50	2.50	13.311	466.17	36.62
8	720	2.29	2.29	13.541	461.87	36.43
9	720	2.00	2.00	13.450	455.23	36.09
10	720	2.50	2.50	12.630	460.70	36.38
avg	720	2.24	2.24	13.053	460.21	36.34
std dev		0.26	0.26	0.617	3.64	0.176

- Minimum 60 minute pre-count delay
- Using 3 grams samples of 41 gm
- Sample ran 5.25 hours on 7/16/97

Table 16 - Appendix A - Series F Counts

#	Count Time (min)	cpm	Corrected cpm for Half-life	SIS	tSIE	Eff. %
1	720	2.60	2.60	12.102	469.65	36.80
2	720	2.77	2.77	12.236	476.72	37.09
3	720	1.97	1.97	13.726	472.48	36.88
4	720	2.24	2.24	13.033	469.78	36.80
5	720	2.04	2.04	13.711	473.28	36.93
6	720	1.87	1.87	14.052	472.31	36.88
7	720	2.78	2.78	12.658	477.06	37.09
8	720	2.01	2.01	14.200	476.14	37.05
9	720	2.35	2.35	12.101	475.93	37.05
10	720	1.74	1.74	14.428	479.18	37.18
avg	720	2.24	2.24	13.225	474.25	36.97
std dev		0.375	0.375	0.908	3.23	0.134

- Minimum 60 minute pre-count delay
- Using 3 grams samples from a 61.8 grams sample
- Ran 13.40 hours from 12/18/97 - 12/19/97

Appendix B - Incinerator Stack Volumetric Flow and Calculations for Release Rate Rates

Table 17 - Incinerator Stack Volumetric Flow Rates

Date and Time of Burn	Volumetric Air Flow Rate, Wet ACFM[1]	Volumetric Air Flow Rate, Wet ACM^2/24 hours
3/9/89 - 1055	5618	229,025
3/9/89 - 1500	6119	249,449
3/9/89 - 1810	5961	243,008
3/9/89 - 930	5573	227,191
3/9/89 - 1345	5930	241,744
3/9/89 - 850	5353	218,222
4/5/89 - 1100	5214	212,556
4/5/89 - 1345	5304	216,224
4/6/89 - 850	4834	197,064
Average	5545	226,053

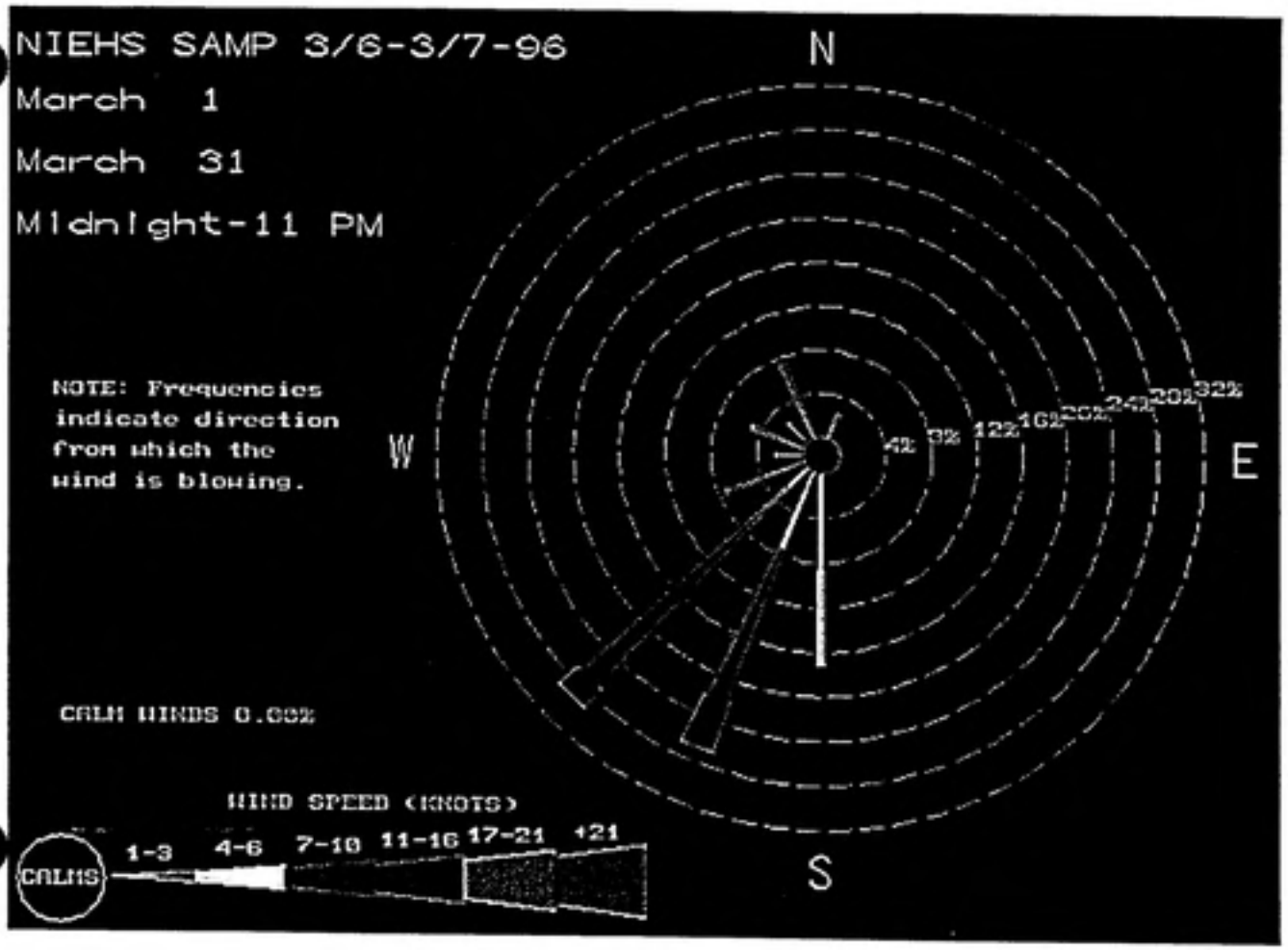
[1]Actual Cubic Feet Minute
[2]Actual Cubic Meters

Calculations for input rate for equations and models

- 47 mCi X 1000 = 47,000 uCi
- 226,053 m^3 X 10 E6 ml/m^3 = 2.26053 E11 ml
- 47,000 uCi / 2.26053 E11 ml = 2.079 E -07 uCi/ml

Appendix C - Wind Roses for Sampling Runs

Series B

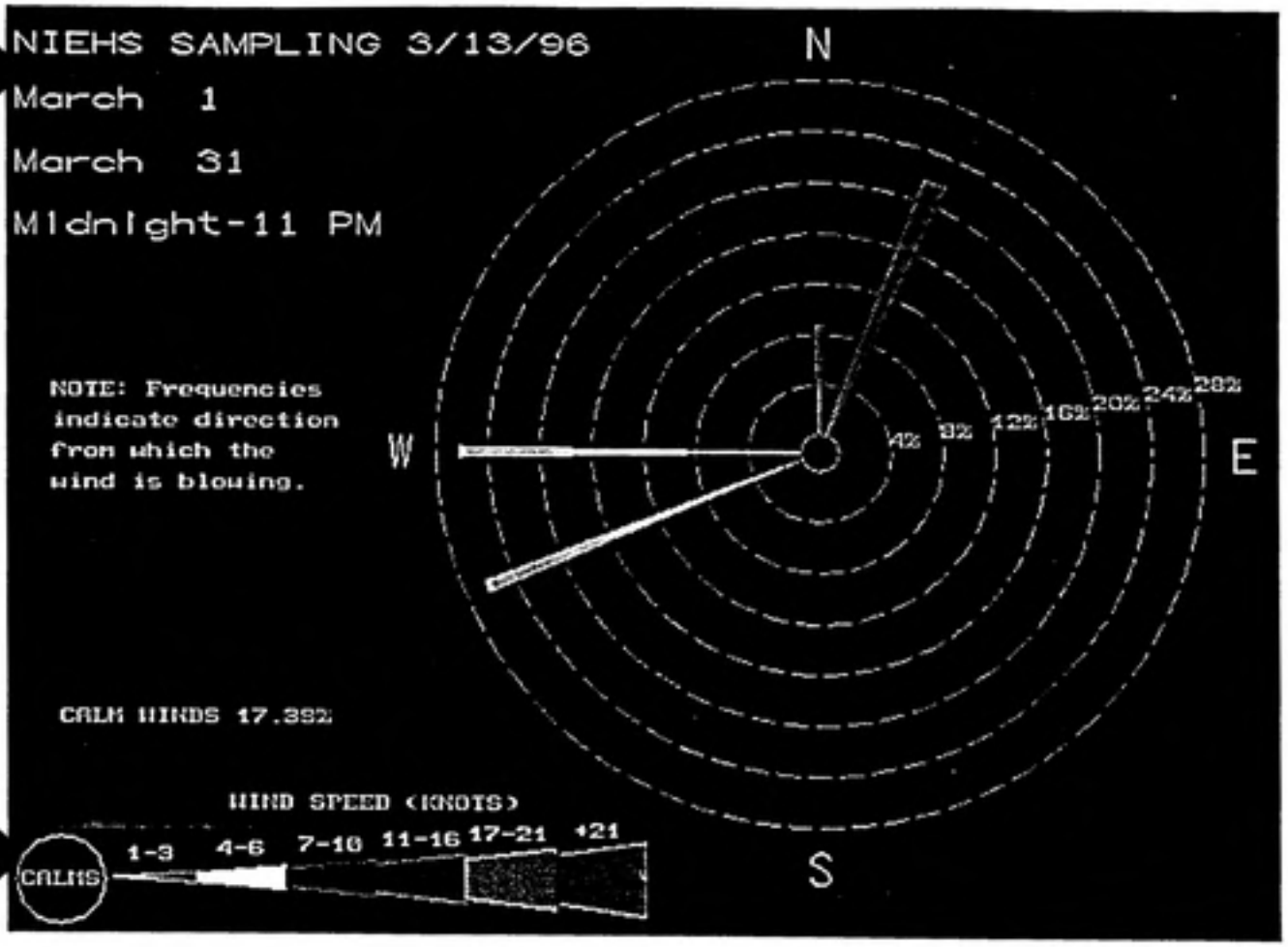

NIEHS SAMP 3/6-3/7-96
March 1
March 31
Midnight-11 PM
NOTE: Frequencies indicate direction from which the wind is blowing.
N
W
E
S
4%
8%
12%
16%
20%
24%
28%
32%
CALM WINDS 0.00%
WIND SPEED (KNOTS)
CALMS
1-3
4-6
7-10
11-16
17-21
>21

NIEHS SAMPLING 3/6/96-3/7/96

Series B

DATE MON	DATE DAY	TIME HR	TIME MIN	WS:AVG MPH	WS:MAX MPH	WD:SDV DEG	WD:AVG DEG	T:AVG DEG
3	6	10	0	5.3	10	23	194	57.3
3	6	10	15	5.3	10	19	192	57.3
3	6	10	30	5.3	11	20	184	57.4
3	6	10	45	5.3	13	17	175	57.6
3	6	11	0	5.6	17	24	186	58.1
3	6	11	15	5.6	16	25	190	58.8
3	6	11	30	5.6	17	24	185	59
3	6	11	45	5.6	19	24	204	59.7
3	6	12	0	7.6	19	21	207	60.5
3	6	12	15	7.6	19	19	210	60.7
3	6	12	30	7.6	20	20	207	61
3	6	12	45	7.6	18	20	211	61.4
3	6	13	0	9.3	19	18	220	61.7
3	6	13	15	9.3	18	19	224	62
3	6	13	30	9.3	24	18	224	62.1
3	6	13	45	9.3	26	18	221	62.5
3	6	14	0	10.5	21	17	224	62.8
3	6	14	15	10.5	27	18	211	62.6
3	6	14	30	10.5	23	19	209	62.8
3	6	14	45	10.5	18	24	198	63
3	6	15	0	9.9	23	25	205	63.6
3	6	15	15	9.9	24	22	210	64.1
3	6	15	30	9.9	18	26	243	64.7
3	6	15	45	9.9	17	22	250	64.8
3	7	11	0	5.5	15	19	189	59.6
3	7	11	15	5.5	17	23	191	60.6
3	7	11	30	5.5	17	21	211	61.2
3	7	11	45	5.5	19	17	223	61.8
3	7	12	0	8.8	17	15	230	62.2
3	7	12	15	8.8	20	18	227	62.2
3	7	12	30	8.8	17	18	230	62.6
3	7	12	45	8.8	16	18	232	62.4
3	7	13	0	7.7	12	16	229	61.9
3	7	13	15	7.7	15	19	228	62.3
3	7	13	30	7.7	13	20	248	63.2
3	7	13	45	7.7	11	18	268	63.1
3	7	14	0	6.7	19	25	283	62.1
3	7	14	15	6.7	25	23	308	59.6
3	7	14	30	6.7	13	38	29	59.6
3	7	14	45	6.7	13	33	15	59
3	7	15	0	7.2	10	26	338	59
3	7	15	15	7.2	9	31	334	58.5
3	7	15	30	7.2	11	40	343	58.1

Series C

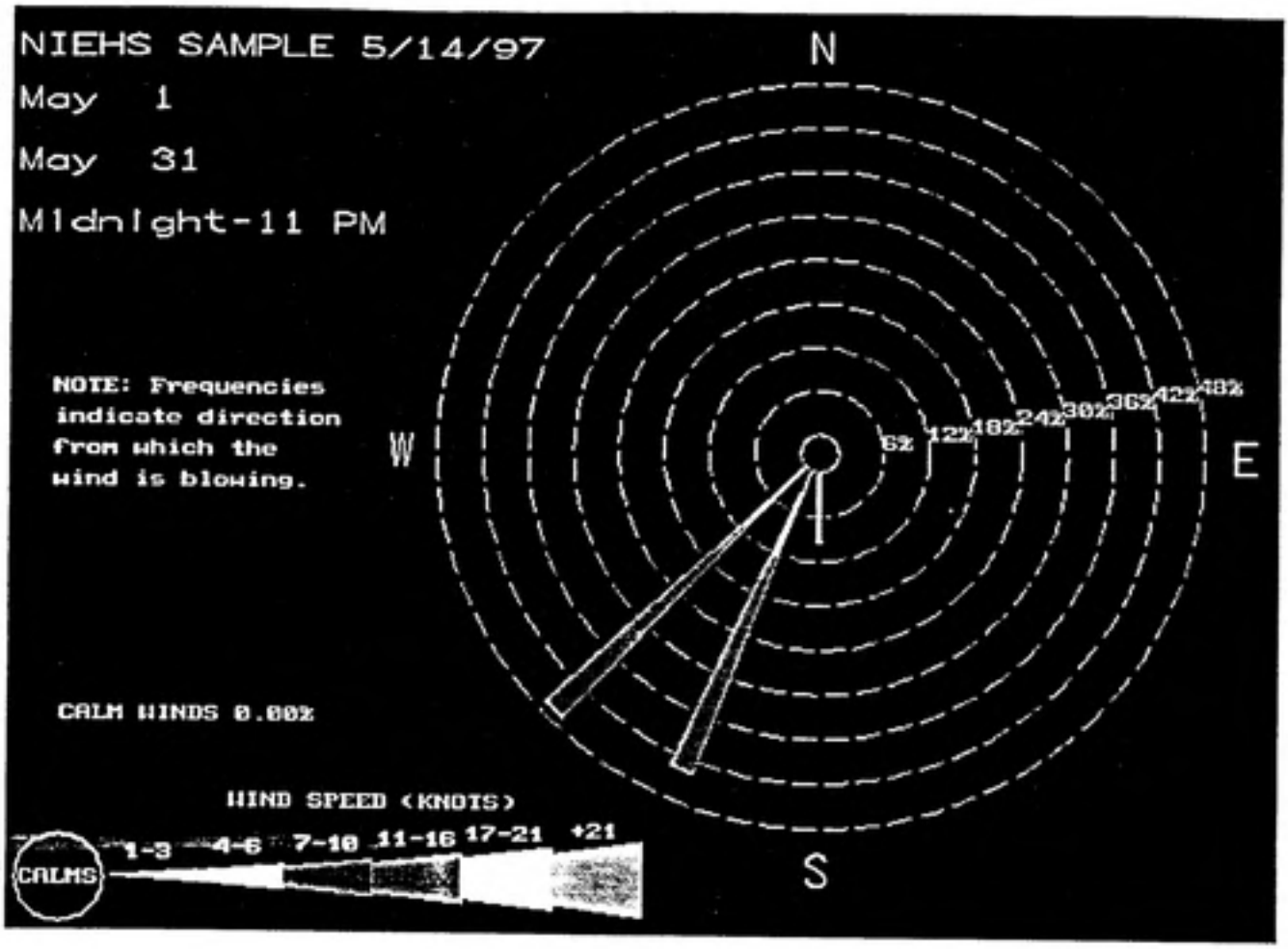

NIEHS SAMPLING 3/13/96
March 1
March 31
Midnight-11 PM
NOTE: Frequencies indicate direction from which the wind is blowing.
N
W
E
S
4%
8%
12%
16%
20%
24%
28%
CALM WINDS 17.38%
WIND SPEED (KNOTS)
CALMS
1-3
4-6
7-10
11-16
17-21
+21

NIEHS SAMPLE 3/12/96-3/14/96

Series C

DATE MON	DATE DAY	TIME HR	TIME MIN	WS:AVG MPH	WS:MAX MPH	WD:SDV DEG	WD:AVG DEG	T:AVG DEG F
3	12	13	0	9.1	20	31	25	51.5
3	12	13	15	9.1	23	23	14	51.7
3	12	13	30	9.1	20	32	18	52.6
3	12	13	45	9.1	20	28	16	52.5
3	12	14	0	9.1	23	29	21	53.4
3	12	14	15	9.1	16	34	37	53.7
3	12	14	30	9.1	19	36	14	54.3
3	12	14	45	9.1	18	32	29	54.3
3	13	10	0	0	0	26	0	0
3	13	10	15	0	9	36	264	52.6
3	13	10	30	0	10	26	268	53.6
3	13	10	45	0	9	24	258	55.2
3	13	11	0	4.6	9	27	254	56.4
3	13	11	15	4.6	15	34	258	56.9
3	13	11	30	4.6	14	33	272	57.9
3	14	10	0	4.2	8	27	254	56.5
3	14	10	15	4.2	8	24	272	58.8
3	14	10	30	4.2	8	20	273	59.7
3	14	10	45	4.2	7	28	247	61.6
3	14	11	0	3.9	8	33	254	63
3	14	11	15	3.9	6	29	270	63.3
3	14	11	30	3.9	9	19	256	65.3
3	14	11	45	3.9	8	30	265	65.2
3	14	12	0	4.1	9	22	241	65.8
3	14	12	15	4.1	7	27	257	67

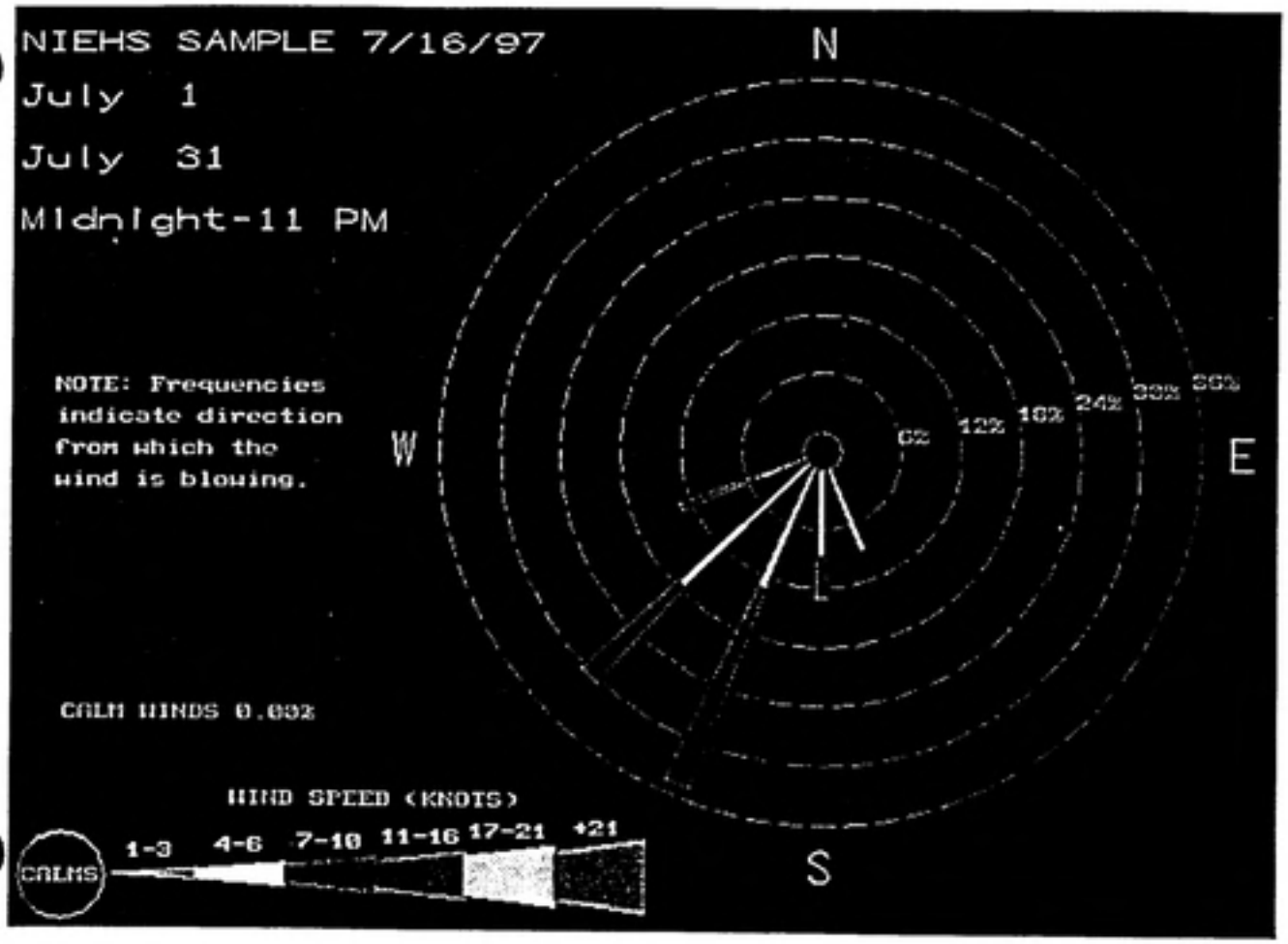
Series D


NIEHS SAMPLE 5/14/97
May 1
May 31
Midnight-11 PM
NOTE: Frequencies indicate direction from which the wind is blowing.
N
W
E
S
6%
12%
18%
24%
30%
36%
42%
48%
CALM WINDS 0.00%
WIND SPEED (KNOTS)
CALMS
1-3
4-6
7-10
11-16
17-21
+21

NIEHS SAMPLE 5/14/97

Series D

DATE MON	DATE DAY	TIME HR	TIME MIN	WS:AVG MPH	WS:MAX MPH	WD:SDV DEG	WD:AVG DEG	T:AVG DEG F
5	14	9	45	2	10	36	204	62.6
5	14	10	0	4.6	11	33	171	63.6
5	14	10	15	4.6	11	31	166	64.8
5	14	10	30	4.6	12	36	184	65.4
5	14	10	45	4.6	14	31	213	66.4
5	14	11	0	6.3	17	32	218	66.9
5	14	11	15	6.3	17	31	219	67.3
5	14	11	30	6.3	15	27	211	68.2
5	14	11	45	6.3	20	37	212	68
5	14	12	0	8.9	21	23	222	68.9
5	14	12	15	8.9	22	30	210	69.2
5	14	12	30	8.9	19	26	207	69.5
5	14	12	45	8.9	18	30	200	70
5	14	13	0	8.6	21	30	186	70.4
5	14	13	15	8.6	21	31	202	71.2
5	14	13	30	8.6	21	33	195	71.3
5	14	13	45	8.6	20	29	209	71.7
5	14	14	0	9.4	21	27	213	72.3
5	14	14	15	9.4	22	17	220	72.5
5	14	14	30	9.4	24	24	193	73.2
5	14	14	45	9.4	18	31	206	74.1
5	14	15	0	9.7	20	29	201	74.3
5	14	15	15	9.7	20	29	224	75.1
5	14	15	30	9.7	22	23	221	75.1
5	14	15	45	9.7	20	25	221	75.5
5	14	16	0	9.9	18	21	217	75.8
5	14	16	15	9.9	17	27	224	76
5	14	16	30	9.9	21	23	215	75.4
5	14	16	45	9.9	20	21	217	75.2
5	14	17	0	9.7	18	23	218	75.7
5	14	17	15	9.7	22	18	226	76
5	14	17	30	9.7	14	20	206	75.8

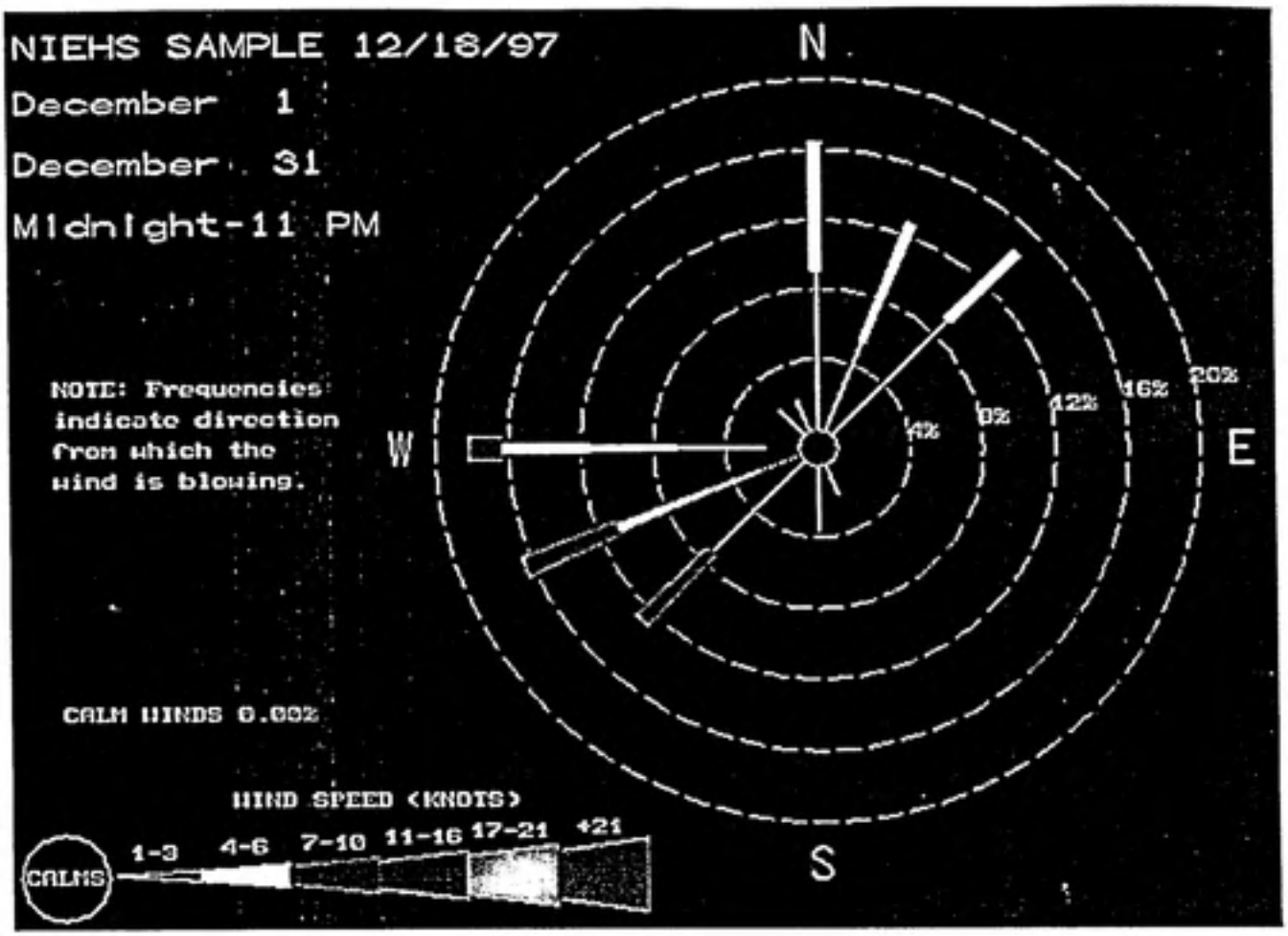

NIEHS SAMPLE 7/16/97
July 1
July 31
Midnight-11 PM
NOTE: Frequencies indicate direction from which the wind is blowing.
N
W
E
S
6%
12%
18%
24%
30%
36%
CALM WINDS 0.00%
WIND SPEED (KNOTS)
CALMS
1-3
4-6
7-10
11-16
17-21
+21

NIEHS SAMPLING 7/16/97

Series E

DATE MON	DATE DAY	TIME HR	TIME MIN	WS:AVG MPH	WS:MAX MPH	WD:STD DEG	WD:AVG DEG	T:AVG DEG F
7	16	10	0	4.3	11	27	227	83
7	16	10	15	4.3	12	24	213	84
7	16	10	30	4.3	10	38	225	85
7	16	10	45	4.3	11	48	237	86
7	16	11	0	4.8	10	29	212	86.4
7	16	11	15	4.8	11	35	199	86.5
7	16	11	30	4.8	12	39	210	87.2
7	16	11	45	4.8	12	36	195	88.3
7	16	12	0	5.4	12	35	173	88.6
7	16	12	15	5.4	12	31	168	89.5
7	16	12	30	5.4	12	28	164	90.2
7	16	12	45	5.4	12	31	173	90.7
7	16	13	0	6.5	15	28	214	91.1
7	16	13	15	6.5	14	29	212	90.9
7	16	13	30	6.5	14	43	213	90.9
7	16	13	45	6.5	12	30	218	91.9
7	16	14	0	6.9	16	35	192	91.5
7	16	14	15	6.9	14	28	201	91.7
7	16	14	30	6.9	17	29	198	91.6
7	16	14	45	6.9	13	23	203	91
7	16	15	0	6.8	16	28	208	92.1
7	16	15	15	6.8	20	39	248	92.5
7	16	15	30	6.8	14	24	237	91.3

Series F


NIEHS SAMPLE 12/18/97
December 1
December 31
Midnight-11 PM
NOTE: Frequencies indicate direction from which the wind is blowing.
N
W
E
S
4%
8%
12%
16%
20%
CALM WINDS 0.00%
WIND SPEED (KNOTS)
CALMS
1-3
4-6
7-10
11-16
17-21
+21

NIEHS SAMPLING 12/18/97 - 12/19/97

Series F

DATE MON	DATE DAY	TIME HR	TIME MIN	WS:AVG MPH	WS:MAX MPH	WD:STD DEG	WD:AVG DEG	T:AVG DEG F	PRECIP 1HR IN
12	18	9	0	2.9	5	16	3	38.7	0.00
12	18	9	15	2.9	11	19	36	39.9	0.00
12	18	9	30	2.9	9	16	33	40.9	0.00
12	18	9	45	2.9	9	18	28	42.0	0.00
12	18	10	0	5	9	16	38	42.4	0.00
12	18	10	15	5	8	18	29	42.8	0.00
12	18	10	30	5	9	17	20	43.6	0.00
12	18	10	45	5	7	29	38	44.8	0.00
12	18	11	0	4.5	9	26	0	45.8	0.00
12	18	11	15	4.5	7	32	1	46.4	0.00
12	18	11	30	4.5	8	12	14	46.9	0.00
12	18	11	45	4.5	8	22	19	47.9	0.00
12	18	12	0	3.8	8	24	36	48.6	0.00
12	18	12	15	3.8	8	30	22	49.5	0.00
12	18	12	30	3.8	7	55	21	50.4	0.00
12	18	12	45	3.8	8	32	26	50.7	0.00
12	18	13	0	3.2	7	42	51	51.3	0.00
12	18	13	15	3.2	8	32	45	51.7	0.00
12	18	13	30	3.2	7	34	16	51.9	0.00
12	18	13	45	3.2	6	41	6	52.3	0.00
12	18	14	0	3.1	6	48	352	52.9	0.00
12	18	14	15	3.1	5	40	48	53.2	0.00
12	18	14	30	3.1	6	55	10	54.0	0.00
12	18	14	45	3.1	5	36	347	54.1	0.00
12	18	15	0	2.3	7	46	259	54.9	0.00
12	18	15	15	2.3	6	30	275	54.5	0.00
12	18	15	30	2.3	5	70	352	54.4	0.00
12	18	15	45	2.3	4	53	314	54.2	0.00
12	18	16	0	1.8	5	31	189	53.7	0.00
12	18	16	15	1.8	4	15	176	53.3	0.00
12	18	16	30	1.8	4	9	164	52.9	0.00
12	19	9	0	3.3	7	11	217	41.3	0.00
12	19	9	15	3.3	7	12	215	42.6	0.00
12	19	9	30	3.3	8	15	218	44.7	0.00
12	19	9	45	3.3	6	17	217	46.3	0.00
12	19	10	0	3.9	7	24	265	48.0	0.00
12	19	10	15	3.9	9	22	264	49.4	0.00
12	19	10	30	3.9	11	23	261	51.0	0.00
12	19	10	45	3.9	9	19	261	52.7	0.00
12	19	11	0	4.9	9	21	255	54.7	0.00
12	19	11	15	4.9	10	22	262	54.7	0.00
12	19	11	30	4.9	12	15	255	56.0	0.00
12	19	11	45	4.9	10	17	255	57.3	0.00
12	19	12	0	5.8	10	25	264	58.0	0.00
12	19	12	15	5.8	12	24	253	59.1	0.00
12	19	12	30	5.8	13	19	240	60.1	0.00
12	19	12	45	5.8	11	25	242	60.5	0.00
12	19	13	0	6.5	15	26	261	60.8	0.00
12	19	13	15	6.5	12	33	255	61.8	0.00
12	19	13	30	6.5	16	23	244	62.4	0.00
12	19	13	45	6.5	15	22	226	62.5	0.00

Series F

12	19	14	0	6.7	14	31	232	62.5	0.00
12	19	14	15	6.7	16	24	243	62.8	0.00
12	19	14	30	6.7	17	18	236	62.3	0.00
12	19	14	45	6.7	16	20	228	62.4	0.00
12	19	15	0	8.6	15	21	233	62.8	0.00

Appendix D - Screen3 & ISCST2 Model Output

```
 ***  SCREEN3 MODEL RUN  ***
 *** VERSION DATED 96043 ***

RESOLUTE

SIMPLE TERRAIN INPUTS:
   SOURCE TYPE               =          POINT
   EMISSION RATE (G/S)       =        1.00000
   STACK HEIGHT (M)          =        11.7800
   STK INSIDE DIAM (M)       =          .5800
   STK EXIT VELOCITY (M/S)=           9.0000
   STK GAS EXIT TEMP (K)     =       945.9600
   AMBIENT AIR TEMP (K)      =       293.0000
   RECEPTOR HEIGHT (M)       =        10.1300
   URBAN/RURAL OPTION        =          RURAL
   BUILDING HEIGHT (M)       =        10.4900
   MIN HORIZ BLDG DIM (M)    =        75.1000
   MAX HORIZ BLDG DIM (M)    =       115.0000

THE REGULATORY (DEFAULT) MIXING HEIGHT OPTION WAS SELECTED.
THE REGULATORY (DEFAULT) ANEMOMETER HEIGHT OF 10.0 METERS WAS ENTERED.


BUOY. FLUX =     5.123 M**4/S**3;  MOM. FLUX =     2.110 M**4/S**2.

*** STABILITY CLASS  4 ONLY ***
*** ANEMOMETER HEIGHT WIND SPEED OF   2.43 M/S ONLY ***

************************************
*** SCREEN AUTOMATED DISTANCES ***
************************************

*** TERRAIN HEIGHT OF     0. M ABOVE STACK BASE USED FOR FOLLOWING DISTANCES ***

  DIST      CONC                 U10M    USTK  MIX HT    PLUME    SIGMA    SIGMA
   (M)   (UG/M**3)    STAB     (M/S)   (M/S)    (M)    HT (M)   Y (M)    Z (M)   DWASH
-------  ----------   ----   -------  -------  ------   ------   ------   ------   -----
    25.    .0000        0        .0       .0       .0      .00      .00      .00    NA

MAXIMUM 1-HR CONCENTRATION AT OR BEYOND     25. M:
     1.    .0000        0        .0       .0       .0      .00      .00      .00

 DWASH=    MEANS NO CALC MADE (CONC = 0.0)
 DWASH=NO  MEANS NO BUILDING DOWNWASH USED
 DWASH=HS  MEANS HUBER-SNYDER DOWNWASH USED
 DWASH=SS  MEANS SCHULMAN-SCIRE DOWNWASH USED
 DWASH=NA  MEANS DOWNWASH NOT APPLICABLE, X<3*LB

**********************************
*** SCREEN DISCRETE DISTANCES ***
**********************************
```

(M)	(UG/M**3)	STAB	(M/S)	(M/S)	(M)	HT (M)	Y (M)	Z (M)	DWASH
50.	1398.	4	2.4	2.5	777.6	16.57	4.31	6.48	SS
40.	2145.	4	2.4	2.5	777.6	15.15	3.50	5.97	SS
60.	945.1	4	2.4	2.5	777.6	18.03	5.11	6.98	SS

DWASH= MEANS NO CALC MADE (CONC = 0.0)
DWASH=NO MEANS NO BUILDING DOWNWASH USED
DWASH=HS MEANS HUBER-SNYDER DOWNWASH USED
DWASH=SS MEANS SCHULMAN-SCIRE DOWNWASH USED
DWASH=NA MEANS DOWNWASH NOT APPLICABLE, X<3*LB

****
*** REGULATORY (Default) ***
PERFORMING CAVITY CALCULATIONS
WITH ORIGINAL SCREEN CAVITY MODEL
(BRODE, 1988)
****

*** CAVITY CALCULATION - 1 ***		*** CAVITY CALCULATION - 2 ***	
CONC (UG/M**3) =	.0000	CONC (UG/M**3) =	.0000
CRIT WS @10M (M/S) =	99.99	CRIT WS @10M (M/S) =	99.99
CRIT WS @ HS (M/S) =	99.99	CRIT WS @ HS (M/S) =	99.99
DILUTION WS (M/S) =	99.99	DILUTION WS (M/S) =	99.99
CAVITY HT (M) =	10.49	CAVITY HT (M) =	10.49
CAVITY LENGTH (M) =	53.80	CAVITY LENGTH (M) =	47.11
ALONGWIND DIM (M) =	75.10	ALONGWIND DIM (M) =	115.00

CAVITY CONC NOT CALCULATED FOR CRIT WS > 20.0 M/S. CONC SET = 0.0

****
END OF CAVITY CALCULATIONS
****

****
*** SUMMARY OF SCREEN MODEL RESULTS ***
****

CALCULATION PROCEDURE	MAX CONC (UG/M**3)	DIST TO MAX (M)	TERRAIN HT (M)
SIMPLE TERRAIN	2145.	40.	0.

****
** REMEMBER TO INCLUDE BACKGROUND CONCENTRATIONS **
****

```
CO STARTING
  TITLEONE Resolute 91
  MODELOPT DFAULT RURAL CONC
  AVERTIME 1 24 PERIOD
  POLLUTID STAND
  TERRHGTS ELEV
  ELEVUNIT FEET
  RUNORNOT RUN
CO FINISHED

SO STARTING
  LOCATION RCRACHE POINT 3.83 -17.65 103.02
  SRCPARAM RCRACHE .002176 11.78 945.96 9.0 .58

  BUILDHGT RCRACHE 9.27 9.27 9.27 9.27 9.27 9.27
  BUILDHGT RCRACHE 9.27 9.27 9.27 9.27 9.27 9.27
  BUILDHGT RCRACHE 9.27 9.27 9.27 9.27 9.27 9.27
  BUILDHGT RCRACHE 9.27 9.27 9.27 9.27 9.27 9.27
  BUILDHGT RCRACHE 9.27 9.27 9.27 9.27 9.27 9.27
  BUILDHGT RCRACHE 9.27 9.27 9.27 9.27 9.27 9.27
  BUILDWID RCRACHE 34.97 39.08 42.01 43.65 43.97 42.96
  BUILDWID RCRACHE 40.64 37.08 32.40 37.08 40.64 42.96
  BUILDWID RCRACHE 43.97 43.65 42.01 39.08 34.97 29.80
  BUILDWID RCRACHE 34.97 39.08 42.01 43.65 43.97 42.96
  BUILDWID RCRACHE 40.64 37.08 32.40 37.08 40.64 42.96
  BUILDWID RCRACHE 43.97 43.65 42.01 39.08 34.97 29.80

  LOCATION MEDPATH POINT 9.01 -17.67 103.02
  SRCPARAM MEDPATH .000000 11.48 1181.14 10.45 .58

  BUILDHGT MEDPATH 9.27 9.27 9.27 9.27 9.27 9.27
  BUILDHGT MEDPATH 9.27 9.27 9.27 9.27 9.27 9.27
  BUILDHGT MEDPATH 9.27 9.27 9.27 9.27 9.27 9.27
  BUILDHGT MEDPATH 9.27 9.27 9.27 9.27 9.27 9.27
  BUILDHGT MEDPATH 9.27 9.27 9.27 9.27 9.27 9.27
  BUILDHGT MEDPATH 9.27 9.27 9.27 9.27 9.27 9.27
  BUILDWID MEDPATH 34.97 39.08 42.01 43.65 43.97 42.96
  BUILDWID MEDPATH 40.64 37.08 32.40 37.08 40.64 42.96
  BUILDWID MEDPATH 43.97 43.65 42.01 39.08 34.97 29.80
  BUILDWID MEDPATH 34.97 39.08 42.01 43.65 43.97 42.96
  BUILDWID MEDPATH 40.64 37.08 32.40 37.08 40.64 42.96
  BUILDWID MEDPATH 43.97 43.65 42.01 39.08 34.97 29.80

  LOCATION CIIT POINT 2400 1400 98.45
  SRCPARAM CIIT .000440972 11.3 1217.0 10.03 .55
```

```
  LOCATION BURR POINT 3500 500 106.68
  SRCPARAM BURR .000625 14.02 1310.78 6.7 .975

  EMISUNIT 1.0E9 MILLICURIES/SEC PICOCURIES/M**3
  SRCGROUP ALL
SO FINISHED

RE STARTING
RE DISCCART 0 -50 340
RE FINISHED

ME STARTING
  INPUTFIL RDU91.UNF UNFORM
  STARTEND 91 01 01  91 12 31
  DAYRANGE 1-365
  ANEMHGHT 6.1
  SURFDATA 13722 1991 RDU
  UAIRDATA 13723 1991 GREENSBORO
ME FINISHED

OU STARTING
  RECTABLE ALLAVE FIRST
  MAXTABLE ALLAVE 10
OU FINISHED


 *** Message Summary For ISC2 Model Setup ***

 --------- Summary of Total Messages --------

A Total of       0 Fatal Error Message(s)
A Total of       1 Warning Message(s)
A Total of       0 Informational Message(s)


  ******** FATAL ERROR MESSAGES ********
         *** NONE ***


  ********  WARNING MESSAGES  ********
SO W320   29 PPARM : Source Parameter May Be Out-of-Range for Parameter     QS

***********************************
*** SETUP Finishes Successfully ***
***********************************
```

*** MODELING OPTIONS USED: CONC RURAL ELEV DFAULT

*** THE SUMMARY OF HIGHEST 1-HR RESULTS ***

** CONC OF STAND IN PICOCURIES/M**3 **

GROUP ID	AVERAGE CONC	DATE (YYMMDDHH)	NETWORK RECEPTOR (XR, YR, ZELEV, ZFLAG)	OF TYPE GRID-ID
ALL	HIGH 1ST HIGH VALUE IS	1520.13900	ON 91110803: AT (.00, -50.00, 103.63, .00)	DC

*** RECEPTOR TYPES: GC = GRIDCART
GP = GRIDPOLR
DC = DISCCART
DP = DISCPOLR
BD = BOUNDARY

*** MODELING OPTIONS USED: CONC RURAL ELEV DFAULT

*** THE SUMMARY OF MAXIMUM PERIOD (8760 HRS) RESULTS ***

** CONC OF STAND IN PICOCURIES/M**3 **

GROUP ID	AVERAGE CONC	NETWORK RECEPTOR (XR, YR, ZELEV, ZFLAG) OF TYPE GRID-ID
ALL	1ST HIGHEST VALUE IS	22.53303 AT (.00, -50.00, 103.63, .00) DC
	2ND HIGHEST VALUE IS	.00000 AT (.00, .00, .00, .00)
	3RD HIGHEST VALUE IS	.00000 AT (.00, .00, .00, .00)
	4TH HIGHEST VALUE IS	.00000 AT (.00, .00, .00, .00)
	5TH HIGHEST VALUE IS	.00000 AT (.00, .00, .00, .00)
	6TH HIGHEST VALUE IS	.00000 AT (.00, .00, .00, .00)

*** RECEPTOR TYPES: GC = GRIDCART
GP = GRIDPOLR
DC = DISCCART
DP = DISCPOLR
BD = BOUNDARY

*** ISCST2 - VERSION 93109 *** *** Resolute 91
*** 02/06/98
***
*** 01:38:36
PAGE 15

*** MODELING OPTIONS USED: CONC RURAL ELEV DFAULT

*** THE SUMMARY OF HIGHEST 24-HR RESULTS ***

** CONC OF STAND IN PICOCURIES/M**3 **

GROUP ID	AVERAGE CONC	DATE (YYMMDDHH)	NETWORK RECEPTOR (XR, YR, ZELEV, ZFLAG)	OF TYPE GRID-ID
ALL	HIGH 1ST HIGH VALUE IS	419.60740	ON 91042024: AT (.00, -50.00, 103.63, .00)	DC

*** RECEPTOR TYPES: GC = GRIDCART
GP = GRIDPOLR
DC = DISCCART
DP = DISCPOLR
BD = BOUNDARY

Appendix E - Incinerator Log Sheets

B

CALIBRATED CO2 MONITOR RE
Id-Clean Out

NIEHS Hazardous Waste Incinerator
Burn Log

Date of Burn	Time of Burn	Name of Operator(s)	Load Number	Weight (Pounds) 23.5 max.	Temperature		Pressure		Notes -- Cl content, smoke, etc.
					Upper 1880 Min.	Lower 1500 Min.	Upper -0.10 Max.	Lower -0.08 Max.	
3-6-96	1022	RE+TI	50 RB	22.5	1586	1548	.20	.10	2 min [illegible] smoke very bl[illegible] shut fire/shut down [illegible]
	1043		54 RB	21.5	2050	1510	.21	.12	
	1125		51 RB	19	2022	1574	.20	.15	
	1140		037 RB	14	2196	1590	.21	.16	
	1155		040 RB	23	2127	1560	.20	.12	
	1228		043 RB	17	2034	1524	.21	.12	
	1302		045 RB	17	2044	1578	.22	.12	
	1312		56 RB	14	2250	1640	.22	.13	
	1334		52 RB	23.5	2119	1570	.22	.13	
	1340		032 RB	23.5	2255	1666	.20	.14	
	1355		055 RB	9	2175	1642	.20	.15	
	1410		38 RB	23.5	2041	1575	.20	.14	
	1528		034 RB	23.5	2032	1575	.22	.13	SMOKE FREE 30 SEC
	1546		57 RB	15	2063	1547	.21	.15	
	1605		031 RB	23.5	2072	1567	.20	.14	
				289.50					

(B)

NIEHS Hazardous Waste Incinerator
Burn Log

Date of Burn	Time of Burn	Name of Operator(s)	Load Number	Weight (Pounds) 23.5 max.	Temperature		Pressure		Notes -- Cl content, smoke, etc.
					Upper 1880 Min.	Lower 1500 Min.	Upper -0.10 Max.	Lower -0.08 Max.	
2-7-96	11:50	RC TI	5 RA	23.5	1968	1547	.20	.12	30 sec smoke/fire
	12:15		044 RA	15.5	2001	1542	.21	.15	1 min smoke/fire
	12:30		046 RA	21	2110	1611	.21	.12	
	12:41		033 RB	23.5	1922	1607	.21	.12	1 min smoke/fire
	13:15		48 RA	23.5	1974	1574	.21	.15	2 min smoke/fire
	13:40		035 RA	16.5	1787	1588	.22	.19	2 min smoke/fire
	14:00		041 RA	18	1983	1508	.21	.14	30 sec smoke/fire
	14:15		036 RA	11.5	1896	1586	.22	.13	
	14:30		026 RA	16	1984	1610	.22	.13	
	14:45		028 RA	18	1968	1611	.22	.14	
	15:00		047 RA	21.5	1848	1580	.22	.13	
	15:15		027 RA	20	2085	1620	.22	.12	
	15:32		49 RA	21	1980	1623	.22	.13	30 sec Smoke
	15:47		042 RA	22	1994	1642	.22	.15	1 min Black smoke & fire
	16:05		39 RA	23.5	2062	1631	.21	.15	1 min Smoke & Fire
				214					

(C) Clean out

NIEHS Hazardous Waste Incinerator
Burn Log

Incinerated Lig Waste

Date of Burn	Time of Burn	Name of Operator(s)	Load Number	Weight (Pounds) 23.5 max.	Temperature		Pressure		Notes -- Cl content, smoke, etc.
					Upper 1880 Min.	Lower 1500 Min.	Upper -0.10 Max.	Lower -0.08 Max.	
5-12-95	1310	Jay / RC	✓60 RB	18	2076	1642	.21	.15	
	1330		✓025 RB	18	2230	1632	.22	.13	
	1345		✓58 RB	12	2096	1591	.22	.15	
	142		✓62 RB	9	2094	1594	.22	.14	
	1430		✓61 RB	13	2048	1591	.22	.13	
	1435		✓021 RB	23.5	2062	1600	.20	.11	Very black + bad smell
				93.50					

(C)

NIEHS Hazardous Waste Incinerator
Burn Log
Burned Liq Waste

Date of Burn	Time of Burn	Name of Operator(s)	Load Number	Weight (Pounds) 23.5 max.	Temperature		Pressure		Notes -- Cl content, smoke, etc.
					Upper 1880 Min.	Lower 1500 Min.	Upper -0.10 Max.	Lower -0.08 Max.	
3-13-96	1005	RE + TJ	64RB	7.5	2026	1686	.22	.14	
	1022		019RB	21	2010	1526	.22	.14	1 in black smoke
	1035		047RB	23.5	2132	1600	.25	.15	
	1047		044RB	22.5	2111	1578	.24	.14	
	1100		022RB	23.5	2055	1570	.22	.13	
			Liq	Waste					
				98					

(C)

NIEHS Hazardous Waste Incinerator
Burn Log

Date of Burn	Time of Burn	Name of Operator(s)	Load Number	Weight (Pounds) 23.5 max.	Temperature		Pressure		Notes -- Cl content, smoke, etc.
					Upper 1880 Min.	Lower 1500 Min.	Upper -0.10 Max.	Lower -0.08 Max.	
3-14-96	10[12]	RC TI	63 BB	9	1987	1518	.20	.09	
	1030		024 RA	18	2000	1569	.21	.11	
	10[04]		020 RA	21	2017	1576	.20	.11	
	11[20]		023 RA	18.5	2003	1574	.21	.10	
	11[55]		018 RA	23.5	2021	1514	.20	.10	
					~~2026~~	1590	~~.21~~	.11	
				90					

(D)

NIEHS Hazardous Waste Incinerator
Burn Log

5-14-97

1-2

Date of Burn	Time of Burn	Name of Operator(s)	Load Number	Weight (Pounds) 23.5 max.	Temperature		Pressure		Notes -- Cl content, smoke, etc.
					Upper 1880 Min.	Lower 1500 Min.	Upper -0.10 Max.	Lower -0.08 Max.	
5-14-97	950	HH ✓	156 RB	22.5	1979	1560	.17	.08	
	1004	HH ✓	149 RB	23	1858	1562	.19	.11	
	1017	HH ✓	150 RB	18.5	1977	1572	.20	.14	
	1030	HH ✓	180 RB	23	1954	1567	.19	.13	
	1047	HH ✓	177 RB	23	1894	1565	.21	.14	
	1059	HH ✓	166 RB	23	1936	1567	.20	.14	
	1112	HH ✓	172 RB	23	1940	1576	.20	.14	
	1125	HH ✓	173 RB	23	2056	1590	.20	.14	
	1137	HH ✓	175 RB	23	2141	1592	.20	.14	
	1150	HH ✓	174 RB	23	2099	1596	.21	.15	
	1207	HH ✓	169 RB	23	2088	1595	.22	.16	
	1218	HH ✓	555-RB	21.5	2141	1639	.21	.14	
	1230	HH ✓	176 RB	23	2149	1634	.21	.14	
	1242	HH ✓	178 RB	23	2093	1583	.20	.15	
	1255	HH ✓	168 RB	21.5	2007	1577	.20	.15	
	1310	HH ✓	157 RB	22.5	2091	1584	.20	.14	
	1325	HH ✓	165 RB	23.5	2086	1570	.20	.14	
	1340	HH ✓	167 RB	18	2182	1690	.20	.14	

(D) 5-14-97

NIEHS Hazardous Waste Incinerator
Burn Log

2-2

Date of Burn	Time of Burn	Name of Operator(s)	Load Number	Weight (Pounds) 23.6 max.	Temperature		Pressure		Notes -- CI content, smoke, etc.
					Upper 1880 Min.	Lower 1500 Min.	Upper -0.10 Max.	Lower -0.08 Max.	
5-14-97	1400	KR	✓164 RR	17	2106	1585	.19	.14	
	1415	KR	✓165 RR	22	2083	1568	.18	.14	
	1430	KR	✓159 RR	23.5	2038	1584	.20	.15	
	1445	KR	✓154 RR	23.5	2104	1581	.21	.15	
	1500	KR	✓164 RR	23.5	2153	1617	.21	.15	
	1530	CC	✓453 RR	23.5	1585	1586	.20	.13	

(E) 7-16-97

NIEHS Hazardous Waste Incinerator
Burn Log

Date of Burn	Time of Burn	Name of Operator(s)	Load Number	Weight (Pounds) 23.5 max.	Temperature		Pressure		Notes -- Cl content, smoke, etc.
					Upper 1880 Min.	Lower 1500 Min.	Upper -0.10 Max.	Lower -0.08 Max.	
7-16-97	1000	HH	*233-RB	23.5	1950	1656	.18	.10	smoke 10 sec
	1014	HH	238-RB	23.5	1956	1700	.18	.11	smoke 20 sec
	1030	HH	234-RB	23.5	2047	1714	.18	.11	
	1043	HH	233-RB	23.5	1902	1648	.19	.16	
	1055	HH	236-RB	23.5	1946	1649	.19	.11	smoke 10 sec
	1107	RC	*213-RA	23.5	1966	1615	.18	.16	
	1120	HH	235-RB	23.5	1931	1575	.19	.11	
	1135	HH	237-RB	23.5	1901	1580	.19	.11	
	1148	HH	232-RB	21.	2047	1671	.19	.12	1 min smoke
	1208	HH	*214-RB	23.5	2035	1686	.19	.12	
	1224	RC	230-RB	22	2025	1682	.18	.10	2 min smoke
	1240	RC	231-RB	21	2013	1644	.19	.11	
	1304	HH	*214-RB	23.5	2017	1667	.19	.11	

(E) 7-17-97

NIEHS Hazardous Waste Incinerator
Burn Log

Date of Burn	Time of Burn	Name of Operator(s)	Load Number	Weight (Pounds) 23.5 max.	Temperature		Pressure		Notes -- Cl content, smoke, etc.
					Upper 1880 Min.	Lower 1500 Min.	Upper -0.10 Max.	Lower -0.08 Max.	
7-17-97	1002	H H	✓240-RB	23.5	1943	1637	.17	.11	Started 2 min
	1015	H H	✓242-RB	23.5	2213	1684	.17	.11	started 10 min
	1028	H H	✓246-RB	23.5	2098	1656	.21	.14	Started 10 min
	1043	H H	✓247-RB	23.5	2008	1618	.20	.12	
	1100	RC	✓243-RB	23.5	1968	1592	.15	.11	
	1115	H H	✓250-RB	23.5	2007	1621	.19	.11	started 20 min
	1130	H H	✓241-RB	23.5	2060	1648	.19	.11	
	1145	H H	✓244-RB	23.5	2035	1627	.19	.11	
	1200	H H	✓251-RB	21	2052	1641	.19	.12	
	1215	H H	✓245-RB	23.5	2102	1633	.19	.12	

(F) 12-18-97

NIEHS Hazardous Waste Incinerator
Burn Log

1 of 2

Date of Burn	Time of Burn	Name of Operator(s)	Load Number	Weight (Pounds) 23.5 max.	Temperature		Pressure		Notes -- Cl content, smoke, etc.
					Upper 1880 Min.	Lower 1500 Min.	Upper -0.10 Max.	Lower -0.08 Max.	
12-18-97	9:31	H H	✓ H19-RB	18.5	1904	1750	.19	.11	
	9:43	H H	✓ H02-RB	15.5	1914	1721	.19	.12	
	9:55	H H	✓ H11-RB	23.5	2134	1855	.21	.14	
	10:07	H H	✓ H09-RB	23.5	2090	1740	.21	.15	
	10:23	H H	✓ H16-RB	17.5	1931	1666	.21	.14	
	10:35	H H	✓ H12-RB	23.5	1871	1660	.19	.12	
	10:48	H H	✓ H10-RB	22.5	2076	1692	.21	.14	
	11:02	H H	✓ H17-RB	18.5	2147	1760	.21	.14	
	11:15	H H	✓ H13-RB	23.5	2201	1821	.21	NS	
	11:28	H H	✓ H24-RB	16.5	2217	1798	.21	.15	
	11:43	H H	✓ H23-RB	20.5	2114	1712	.19	.14	
	11:56	H H	✓ H02-RB	23.5	2151	1711	.21	.15	
	12:08	H H	✓ H20-RB	20.5	2215	1787	.21	.15	
	12:22	H H	✓ H10-RB	23.5	2192	1719	.21	.15	
	12:35	H H	✓ H30-RB	23.5	2201	1752	.20	.15	
	12:47	H H	✓ H21-RB	17.5	2147	1713	.21	.15	
	13:00	H H	✓ H18-RB	15.5	2152	1689	.21	.14	
	13:14	H H	✓ H31-RB	23.5	2149	1690	.21	.14	

(F)

12-18-97

NIEHS Hazardous Waste Incinerator
Burn Log

Date of Burn	Time of Burn	Name of Operator(s)	Load Number	Weight (Pounds) 23.5 max.	Temperature		Pressure		Notes -- Cl content, smoke, etc.
					Upper 1880 Min.	Lower 1500 Min.	Upper -0.10 Max.	Lower -0.08 Max.	
12-18-97	1325	H H	✓ H33-RB	23.5	2220	1755	.21	.14	
	1341	H H	✓ H06-RB	23.5	2259	1752	.21	.15	
	1355	H H	✓ H04-RB	17.5	2202	1660	.21	.15	
	1409	H H	✓ H07-RB	17.0	2275	1773	.21	.15	
	1422	H H	✓ H32-RB	23.5	2267	1757	.20	.14	
	1435	H H	✓ H14-RB	23.5	2252	1714	.19	.14	
	1450	H H	✓ 349-RB	19.0	2253	1701	.21	.15	
	1503	H H	✓ H25-RB	21.5	2247	1693	.21	.16	
	1515	H H	✓ H08-RB	23.5	2226	1719	.22	.16	
	1530	H H	✓ 391-RB	21.5	2274	1772	.22	.16	

Radioactive Waste Incineration Log

B

Background Exposure Rate	0.01
Incinerator T12 (1)	X
T12 (2)	
Total number of containers	30

Weight	584.5
32P	0.000000
33P	0.000000
14C	0.892050
3H	1.008070
35S	0.000000
125I	0.000000
45Ca	0.000000

Date: March 5, 1996

Name: [signature]

	Container #	Weight	32P	33P	14C	3H	35S	125I	45Ca	Comments
✓	57-96-RB	15.0				0.001000				FLAMMABLE
✓	56-96-RB	14.0				0.001000				FLAMMABLE
✓	55-96-RB	9.0				0.000500				FLAMMABLE
✓	54-96-RB	21.5			0.002500	0.005000				FLAMMABLE
✓	53-96-RB	23.5			0.002500	0.017500				FLAMMABLE
✓	52-96-RB	23.5			0.002500	0.017500				FLAMMABLE
✓	51-96-RB	19.0			0.128425	0.128425				FLAMMABLE
✓	50-96-RB	22.5			0.128425	0.128425				FLAMMABLE
✓	49-96-RB	21.0			0.100000					
✓	48-96-RB	23.5				0.030000				
✓	47-96-RB	21.5								
✓	46-96-RB	21.0			0.150000					
✓	45-96-RB	17.0			0.150000					
✓	44-96-RB	15.5			0.200000					FLAMMABLE
✓	43-96-RB	17.0				0.004220				FLAMMABLE
✓	42-96-RB	22.0			0.000200	0.002500				FLAMMABLE
✓	41-96-RB	18.0			0.008000					FLAMMABLE
✓	40-96-RB	23.0			0.008000					FLAMMABLE
✓	39-96-RB	23.5								FLAMMABLE
✓	38-96-RB	23.5				0.052000				FLAMMABLE
✓	37-96-RB	14.0			0.006000	0.162000				
✓	36-96-RB	11.5			0.001000	0.250000				CORROSIVE
✓	35-96-RB	16.5			0.002500	0.038000				FLAMMABLE
✓	34-96-RB	23.5			0.002000	0.039000				FLAMMABLE
✓	33-96-RB	23.5				0.101000				FLAMMABLE
✓	32-96-RB	23.5				0.024000				FLAMMABLE
✓	31-96-RB	23.5				0.003000				FLAMMABLE
✓	28-96-RB	18.0				0.001000				
✓	26-96-RB	16.0				0.001000				
✓	27-96-RB	20.0				0.001000				

Radioactive Waste Incineration Log

C

Background Exposure Rate	0.01
Incinerator T12 (1)	X
T12 (2)	
Total number of containers	16

Weight	281.5
32P	0.000000
33P	0.000000
14C	0.074260
3H	96.613790
35S	0.009000
125I	0.000000
45Ca	0.000000

Date: March 11, 1996

Name: Spence Albright

	Container #	Weight	32P	33P	14C	3H	35S	125I	45Ca	Comments
✓	60-96-RB	18.0				0.001000				
✓	61-96-RB	13.0			0.000130	0.001000				
✓	58-96-RB	12.0			0.004900	0.100000				
✓	18-96-RB	23.5			0.009630	0.001000				
✓	19-96-RB	21.0			0.021000	0.500000	0.009000			
✓	14-96-RB	22.5				0.001000				NON-REG
✓	22-96-RB	23.5				0.001000				
✓	20-96-RB	21.0			0.031100	0.004790				
✓	21-96-RB	23.5			0.007500					
✓	17-96-RB	23.5				0.001000				NON REG
✓	25-96-RB	18.0				0.001000				
✓	24-96-RB	18.0				0.001000				
✓	23-96-RB	18.5				0.001000				
✓	62-96-RB	9.0				32.00000				CORROSIVE
✓	63-96-RB	9.0				32.00000				CORROSIVE
✓	64-96-RB	7.5				32.00000				CORROSIVE

Radioactive Waste Incineration Log

D

Background Exposure Rate		0.02
Incinerator	T12 (1)	X
	T12 (2)	
Total number of containers		24

Weight	538.0
32P	0.001400
33P	0.000000
14C	5.574500
3H	12.053000
35S	0.734000
125I	0.000000
45Ca	0.000000

Date: MAY 13, 1997

Name:

Container #	Weight	32P	33P	14C	3H	35S	125I	45Ca	Comments
166-97-RB	23.0			0.00727		0.20000			NON-REG
149-97-RB	23.0			0.04000	0.05000	0.12000			NON-REG
165-97-RB	23.5			0.30000		TRACE			NON-REG
164-97-RB	23.5	0.00100				0.06400			CORROSIVE
154-97-RB	23.5			0.03000					NON-REG
156-97-RB	23.5			0.11000					FLAMMABLE
155-97-RB	22.0			0.00020					FLAM
150-97-RB	18.5			0.03000	TRACE				NON-REG
159-97-RB	23.5			4.50000					NON-REG
157-97-RB	23.5			0.50000					NON-REG
158-97-RB	23.5			0.01500					FLAMMMABLE
180-97-RB	23.0				12.0010				NON-REG
178-97-RB	23.0	0.00010							NON-REG
177-97-RB	23.0	0.00010							NON-REG
176-97-RB	23.0	0.00010							NON-REG
175-97-RB	23.0	0.00010							NON-REG
173-97-RB	23.0				0.00100				FLAM
172-97-RB	23.0				0.00100				FLAM
174-97-RB	23.0				0.00100				FLAM
168-97-RB	17.0			0.01600					FLAM
167-97-RB	18.0			0.01600					FLAM
169-97-RB	23.0		0.01000						NON-REG
555-96-RB	21.5					0.10000			FLAM
453-96-RB	23.5	TRACE				0.25000			FLAM

Radioactive Waste Incineration Log

E

Background Exposure Rate	
Incinerator T12 (1)	X
T12 (2)	
Total number of containers	12

Weight	275.5
32P	
33P	
14C	0.333000
3H	4.300000
35S	2.236000
125I	
45Ca	

Date: July 14, 1997

Name:

Container #	Weight	32P	33P	14C	3H	35S	125I	45Ca	Comments
223-97-RB	23.5					0.05000			CORROSIVE
211-97-RB	23.5					0.77600			CORR(ACID)
213-97-RB	23.5			TRACE		0.41000			FLAM
236-97-RB	23.5			0.01500					FLAM/POI/CORR
232-97-RB	21.0			0.03000					FLAM
231-97-RB	21.0			0.03000	4.30000				FLAM
234-97-RB	23.5			0.01500					NR
233-97-RB	23.5			0.01500					NON-REGULATED
235-97-RB	23.5			0.01500					NON-REGULATED
230-97-RB	22.0			0.03500					FLAM
238-97-RB	23.5			0.10000					NR
214-97-RB	23.5			0.00300		1.00000			NON-REGULATED

Radioactive Waste Incineration Log

E

Background Exposure Rate	0.02
Incinerator T12 (1)	X
T12 (2)	
Total number of containers	10

Weight	232.5
32P	0.000000
33P	0.000000
14C	0.950000
3H	0.001000
35S	0.020000
125I	
45Ca	

Date: July 17, 1997

Name:

Container #	Weight	32P	33P	14C	3H	35S	125I	45Ca	Comments
242-97-RB	23.5			0.00200					NON-REGULATED
246-97-RB	23.5			0.00200					NON-REGULATED
247-97-RB	23.5			0.00200					NON-REGULATED
243-97-RB	23.5			0.00200					NON-REGULATED
250-97-RB	23.5			0.20600					FLAMMABLE
241-97-RB	23.5			0.00100					NON-REGULATED
244-97-RB	23.5			0.00200					NON-REGULATED
251-97-RB	21.0			0.72500	0.00100				FLAMMABLE
245-97-RB	23.5			0.00200					NON-REGULATED
240-97-RB	23.5			0.00600		0.02000			FLAMMABLE

Radioactive Waste Incineration Log

F

Background Exposure Rate	0.02
Incinerator T12 (1)	X
T12 (2)	
Total number of containers	28

Weight	587.5
32P	0.000000
33P	0.000000
14C	0.325430
3H	18.818600
35S	3.160000
125I	0.000000
45Ca	0.000000

Date: Dec. 18, 1997

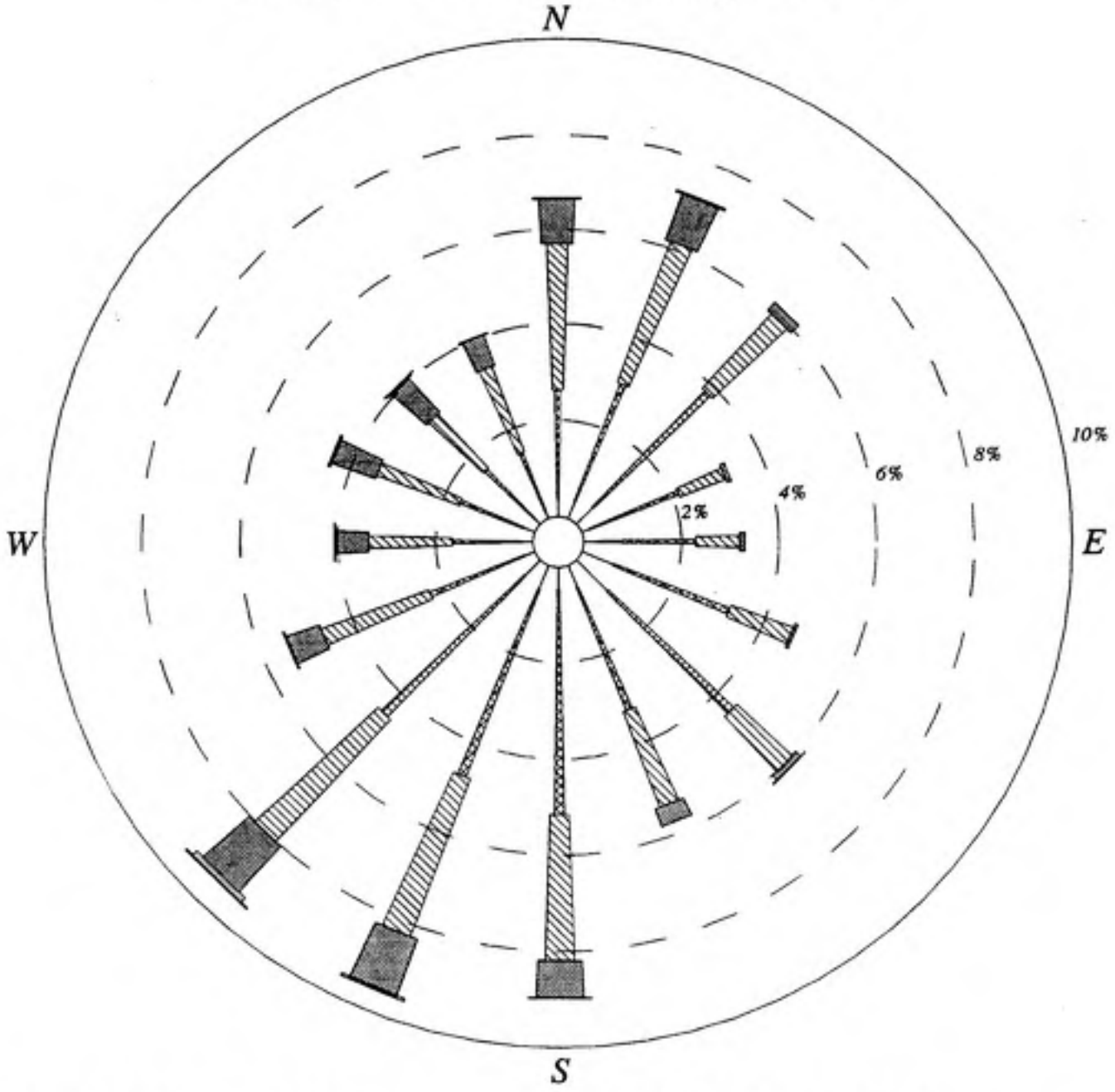
Name:

Container #	Weight	32P	33P	14C	3H	35S	125I	45Ca	Comments
404-97-RB	17.5			trace					FLAM
425-97-RB	21.0			trace					NON-REG
406-97-RB	23.5			trace					FLAM
424-97-RB	16.5			0.02000					FLAM
430-97-RB	23.5			0.00180	0.00400				NON-REG
391-97-RB	23.5				0.00100				FLAM
418-97-RB	15.5			0.01000					FLAM
349-97-RB	19.0			trace	8.10000				FLAM
431-97-RB	23.5			0.00183	0.00460				NON-REG
432-97-RB	23.5			0.00090	0.00200				NON-REG
416-97-RB	17.5			0.03000					FLAM
420-97-RB	20.5			0.06000					FLAM
423-97-RB	20.5			0.04000					FLAM/POISON
414-97-RB	23.5				10.0000				NON-REG
417-97-RB	18.5			0.04000					FLAM
419-97-RB	18.5			0.03000					FLAM
407-97-RB	17.0			trace					FLAM
410-97-RB	23.5				0.00100				FLAM
421-97-RB	17.5			0.03000					FLAM
422-97-RB	15.5			0.02000					FLAM
412-97-RB	23.5				0.00100				FLAM
409-97-RB	23.5				0.00100				FLAM
411-97-RB	23.5				0.00100				FLAM
408-97-RB	23.5				0.00100				FLAM
413-97-RB	23.5				0.09200	0.86000			FLAM
360-97-RB	23.5				0.500000	0.800000			CORR(ACID)
426-97-RB	23.5			0.040000	0.108000	0.600000			NON-REG
433-97-RB	23.5			0.000900	0.002000	0.900000			NON-REG

Appendix F - Raleigh-Durham Wind Roses

Raleigh 1988

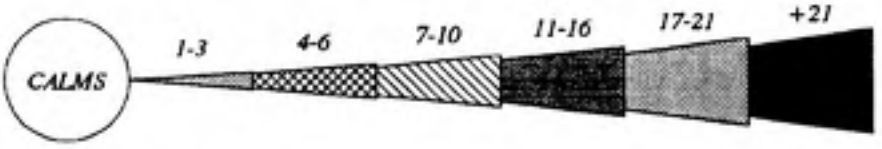
January 1-December 31; Midnight-11 PM



CALM WINDS 6.60%

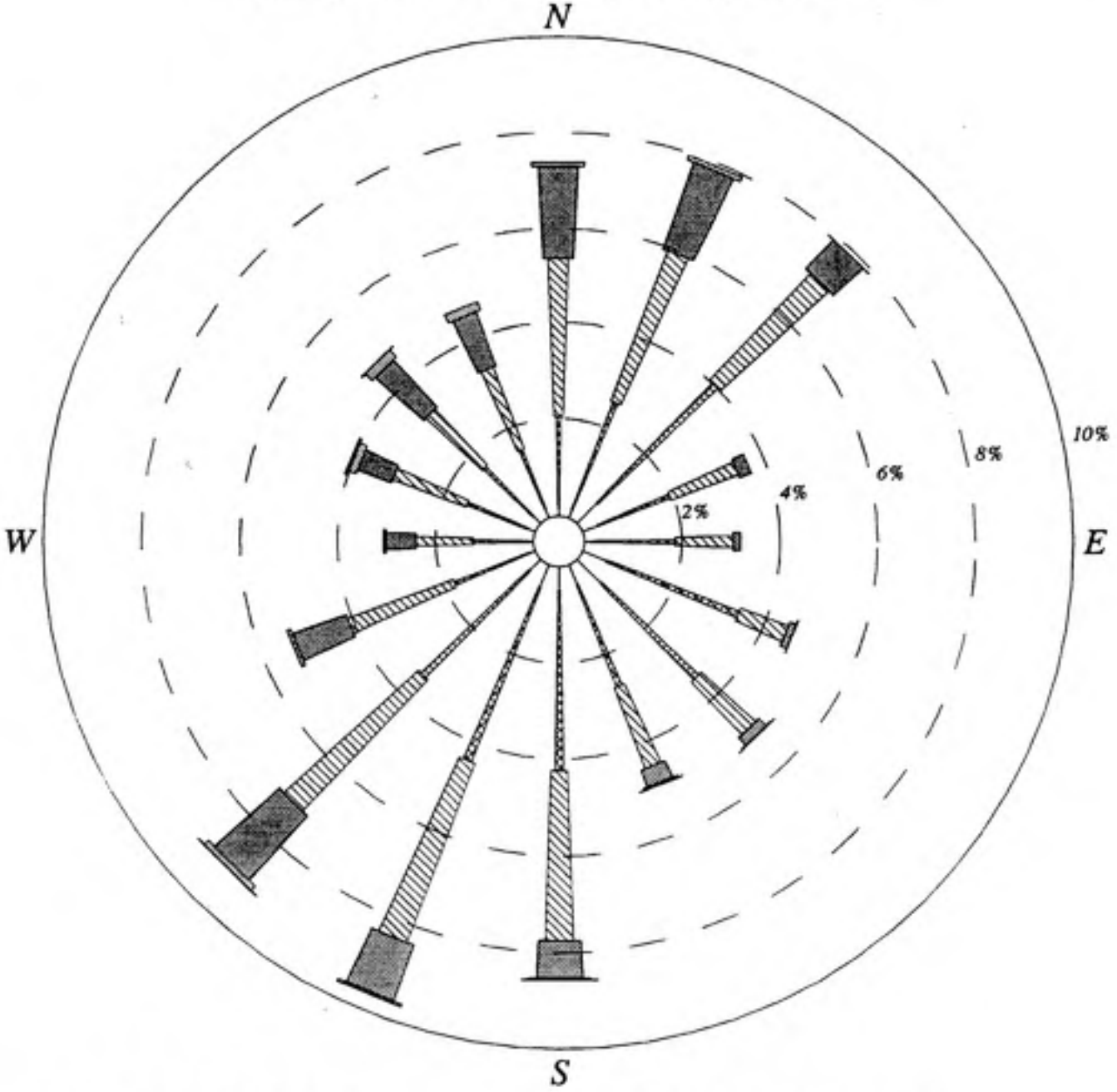
NOTE: Frequencies indicate direction from which the wind is blowing.

WIND SPEED (KNOTS)



Raleigh 1989

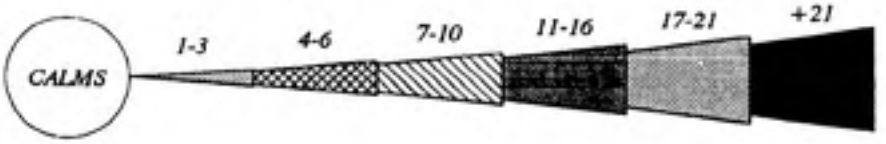
January 1-December 31; Midnight-11 PM



CALM WINDS 5.83%

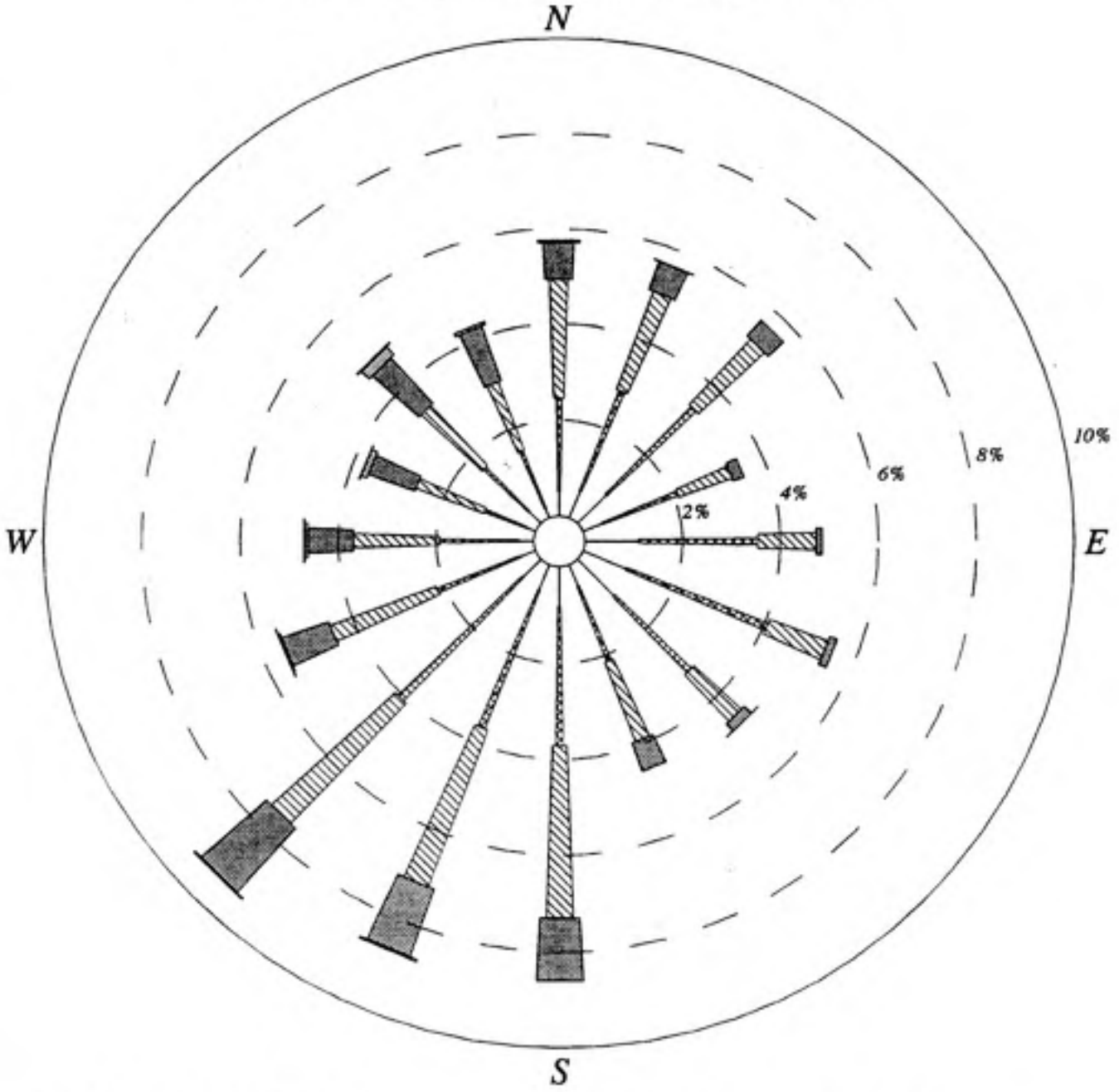
WIND SPEED (KNOTS)

NOTE: Frequencies indicate direction from which the wind is blowing.



Raleigh 1990

January 1-December 31; Midnight-11 PM



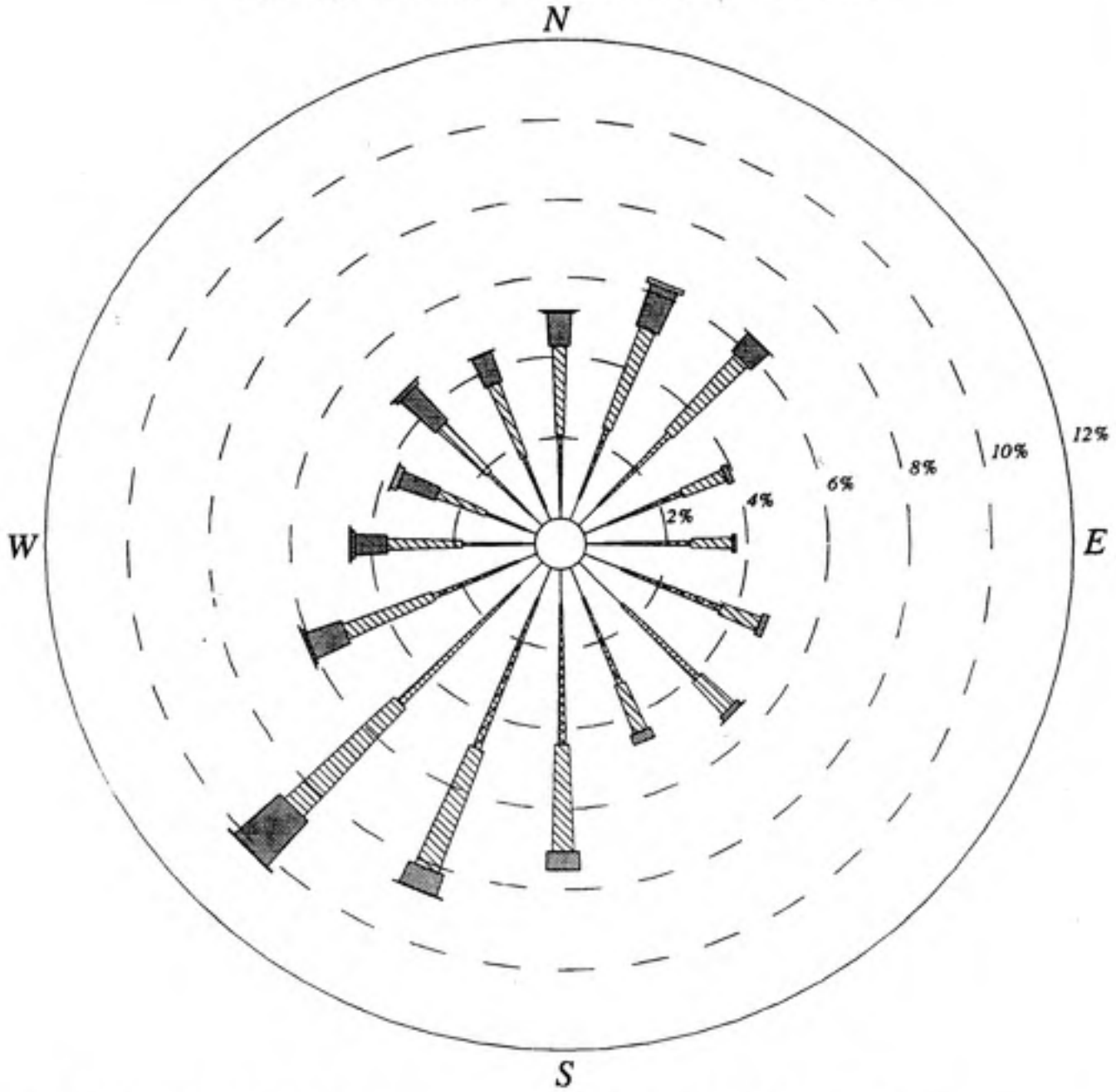
CALM WINDS 9.86%

NOTE: Frequencies indicate direction from which the wind is blowing.

WIND SPEED (KNOTS)

Raleigh 1991

January 1-December 31; Midnight-11 PM



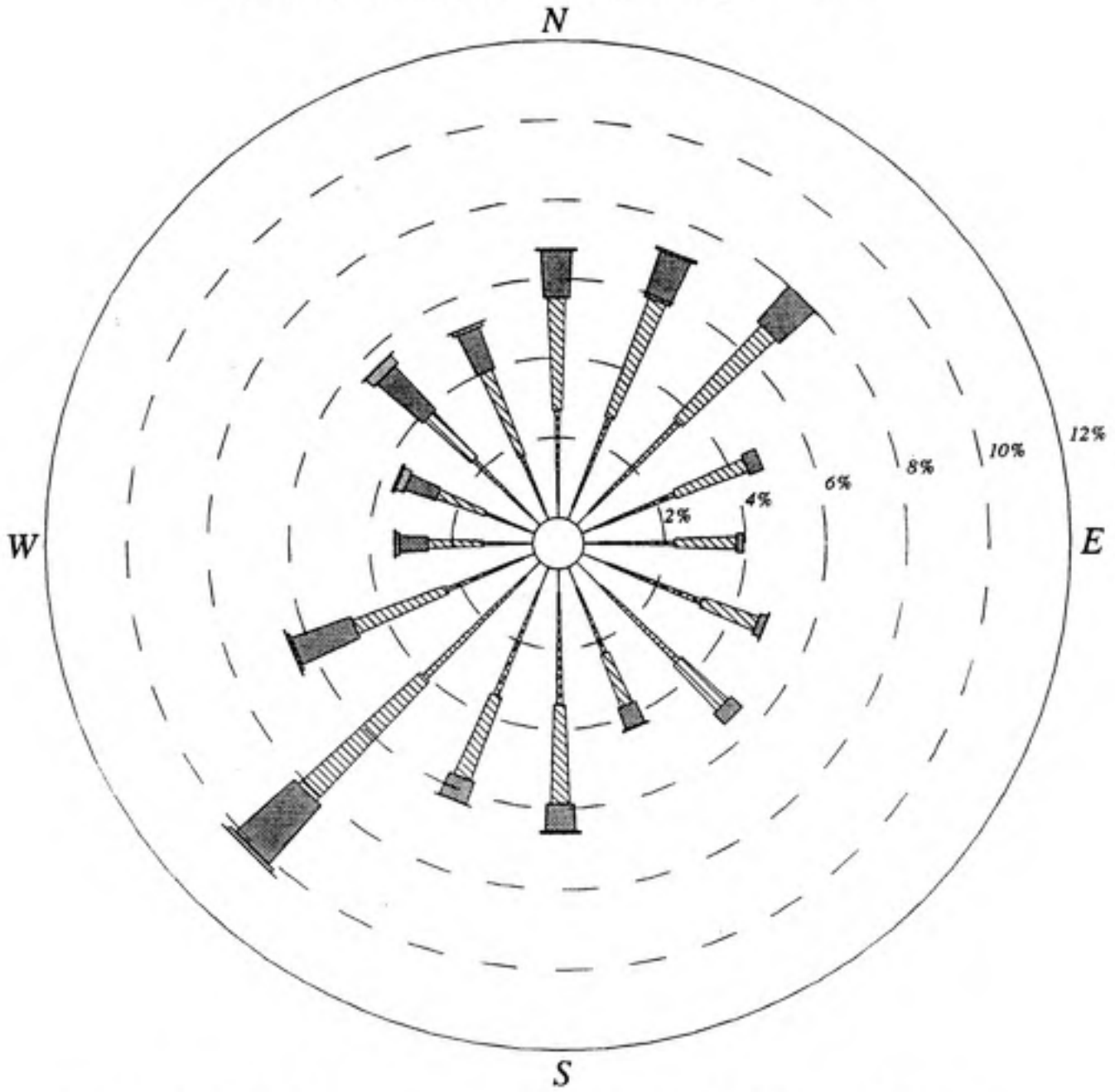
CALM WINDS 9.25%

WIND SPEED (KNOTS)

NOTE: Frequencies indicate direction from which the wind is blowing.

Raleigh 1992

January 1-December 31; Midnight-11 PM



CALM WINDS 7.02%

NOTE: Frequencies indicate direction from which the wind is blowing.

WIND SPEED (KNOTS)